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Quality and Storage Life of Ground Beef

by

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©

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled **Quality and Storage Life of Ground Beef** submitted by Julie Patricia Prokuda in partial fulfillment of the requirements for the degree of **Master of Science in Food Science and Technology**.

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DEDICATION

To Mom, Dad and Natalka

ABSTRACT

Three handling systems for the preparation of ground beef (in-store ground, central coarse ground and central fine ground) were evaluated to determine their effect on the microbiological and sensory quality of ground beef. A survey of samples obtained from the retail market indicated that grinding of beef in the store resulted in products with the highest microbial load. However, a trained panel found that the in-store ground beef samples had the lowest intensity of off-odours compared with ground beef that had been packaged in a central facility. A consumer panel found that in-store ground samples were more acceptable than the central coarse or central fine ground beef samples. A storage study designed to compare the quality of ground beef prepared by the three handling systems demonstrated that in-store ground beef and chub packaged coarse ground beef (to be finely ground in the retail store) had the longest storage life and highest consumer acceptance.

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1. INTRODUCTION

Meat processors are increasingly concerned with the microbiological and sensory quality of ground beef products. In the past, most ground beef was prepared as it was needed for display and sale in the retail store. Presently, ground beef may be prepared in the retail store from beef trim that accumulates from the cutting of primal cuts into retail cuts, or it may be made from trim prepared and packaged in a large packing plant. To reduce the contamination of ground beef and extend its storage life, processors have used new packaging technology for centralized preparation and packaging of ground beef where beef is ground in a central facility and distributed to the retail marketplace as either coarse ground beef or retail-ready ground beef products. The packaging technology used for centralized preparation creates an environment for the product that has a lower oxygen content than traditional in-store packages, lengthening the storage life of the product (Borch et al., 1996). It has been demonstrated that centralized production of ground beef results in a product of superior microbiological quality (Shoup and Oblinger, 1976). However, there are no studies in the research literature that compare the microbiological and sensory quality of ground beef prepared by different handling methods.

Meat spoilage at the retail counter is estimated to account for 55% of the total spoilage losses sustained by the meat industry (Breidenstein, 1986). Thus, any improvements in handling and packaging processes that will extend the storage life of ground beef are of high economic importance to the meat industry.

Currently there are three methods available to industry for preparation of ground beef. The first handling system involves grinding beef trim and packaging the ground beef in the retail store. Beef trim is fine ground in the store and is placed on a styrofoam tray and overwrapped with oxygen permeable film for retail display. This ensures the product

maintains a bright cherry red colour for presentation to the consumer. The second handling system is a partially centralized process where beef trim is coarse ground and packaged in a centralized facility and transported to the retail outlet where it is fine ground, placed on a styrofoam tray and overwrapped with oxygen permeable film. To the consumer, it is not apparent when buying ground beef on a styrofoam tray whether the ground beef was prepared in the retail store or if it was prepared from a product that was coarse ground in a central facility. The third handling system is a completely centralized process that removes the need for grinding and packaging in the retail outlet. Beef trim is coarse and fine ground and packaged in a centralized facility. The product is then shipped to the retail stores as retail-ready ground beef and is presented to the consumer in opaque packaging (chub packages).

The microbiology of ground beef can be extremely variable depending on the source of the meat, the type of packaging, the storage temperature and the storage time. Ground beef produced from trimmings in the retail store can have a total bacterial load that ranges from 10^3 to more than 10^7 colony forming units (CFU) per gram (Duitschaever et al., 1973). However, the impact of the total number of bacteria on the eating quality of ground beef will depend on the storage atmosphere.

Prior to the use of vacuum packaging technology for distribution of meats, ground beef prepared in the retail market would have a microflora composed primarily of gram negative bacteria, mainly *Pseudomonas* spp. However, with the use of new packaging technologies, the microflora of ground beef would be expected to primarily be composed of lactic acid bacteria. The type of microflora that is present on ground beef can have a dramatic effect on the sensory quality of the product. Aerobically stored product would be expected to spoil rapidly due to the production of amines, sulphides and esters by

Pseudomonas spp. (Gill and Greer, 1993; Dainty and Mackey, 1992). Anaerobically packaged meat would be expected to have a longer storage life but it would eventually spoil due to the production of lactic and acetic acids by lactic acid bacteria (Sutherland et al., 1976). In some cases, *Brochothrix thermosphacta* may grow on vacuum packaged ground beef and would cause the development of a cheesy odour (Borch et al., 1996; Mattila-Sandholm and Skyttä, 1990; Gardner, 1980).

The sensory quality and consumer acceptability of ground beef is determined by its colour, odour and flavour. The colour of raw ground beef will determine whether consumers purchase aerobically packaged product. However, when ground beef is prepared as retail ready chub packages, the opaque packaging does not allow the consumer to see the product. In this case, purchase decisions are not based on product appearance, however, when the package is opened the appearance will influence consumers perception of product acceptability. Once packages of ground beef are opened, the odour of the product will affect a consumers perception of quality (Lynch et al., 1986), which may influence future purchasing decisions. Recent reports in the news media have expressed concerns that retail ready chub packages of ground beef are not as "fresh" as ground beef prepared in the retail stores. However, there are very few reports in the scientific literature on the sensory quality of ground beef offered for retail sale. Furthermore, there have been no comparisons made of the quality and consumer acceptability of ground beef prepared by the three handling systems.

This study was designed to determine how variations in packaging systems of ground beef would influence the microbiological and sensory quality and consumer acceptance of ground beef. This was done to compare the quality of ground beef prepared by the three handling systems and offered for sale in the retail marketplace. To more accurately compare the effects of handling and packaging systems on quality of ground

beef prepared by the three handling systems, a controlled storage life study was done. It is anticipated that the information gathered in this study will be used by the meat industry to make informed decisions on the choice of packaging system(s) that will maximize the storage life of ground beef, thereby reducing economic losses due to spoilage.

2. LITERATURE REVIEW

Ground Beef Quality

There are several factors that contribute to the spoilage susceptibility of ground beef, including the initial quality and bacteriology of the meat, storage atmosphere and temperature. These parameters will influence the quality of the product in terms of the appearance (colour) and odour and flavour characteristics of the product offered to the consumer.

The bacteria present in fresh ground beef are introduced by contaminants on the hide of the carcass and in the contents of the gastrointestinal tract, and by workers and meat processing equipment. Bacteria present on the meat surface become distributed throughout the product during the grinding process. Initially, a variety of different bacteria are present in ground beef and their growth may be discouraged by storage conditions. For instance, the growth of mesophilic organisms will be controlled by proper chill storage temperatures (≤4°C), however, psychrotrophic organisms will grow at this temperature. Borch et al. (1996) reported that only ten percent of the bacteria initially present on fresh meat are able to grow at refrigeration temperatures, and the fraction that causes meat spoilage is even lower. Beef has a high water activity and a pH of 5.6 to 5.8, which are favourable for the growth of most bacteria. Meat also contains the nutrients, minerals and growth factors that are essential for microbial growth (Hammes et al., 1990). The amount of contamination on ground beef at the time of packaging will also influence the length of storage time prior to the onset of spoilage. The higher the initial microbial load on meat, the shorter the storage life (Ayres, 1960; Reagan et al., 1973; McMullen and Stiles, 1993).

The appearance of fresh meat is very important to the consumer and heavily influences meat purchase decisions. Adams and Huffman (1972) conducted a study on packaged pork quality and found that consumers related the colour of muscle tissue to freshness. In the 1950's, researchers (Pirko and Ayres, 1957) found that consumers equated the bright red colour of beef to indicate freshness and quality. Today's consumer also equates the bright red colour of beef with freshness of the product (Chambers and Bowers, 1993). Fresh meat colour depends on the relative amounts of three forms of myoglobin (Young et al., 1988). Reduced myoglobin is the predominant muscle pigment in the absence of oxygen (Seideman et al., 1984). It is responsible for the purple-red colour observed when meat is first cut or when meat is vacuum packaged. Oxymyoglobin is the oxygenated form of the muscle pigment and it is responsible for the bright red colour consumers expect in the retail marketplace. Low storage temperatures suppress the residual activity of oxygen-utilizing enzymes (Lawrie, 1974) and inhibit the deoxygenation of oxymyoglobin. Hence, low storage temperatures in the retail cases preserve the colour of fresh meat. Metmyoglobin is the reduced form of myoglobin that is responsible for an undesirable brown colour. It is formed by oxidation of oxymyoglobin and reduced myoglobin in low oxygen tension, and at low pH or high temperatures (Renerre and Labadie, 1993). Many factors contribute to discoloration, referred to by the meat industry as loss of bloom, and the consumer will usually relate this to bacterial growth and spoilage, which is not always the case (Seideman et al., 1984).

The intrinsic properties of meat, such as pH will influence meat colour. The two extremes that demonstrate the influence of muscle pH on colour are pale, soft and exudative (PSE) and dark, firm and dry (DFD) meat. PSE meat results from extreme stress of the animal immediately prior to slaughter, which causes the metabolic rate, including the rate of glycolysis, to increase. Rapid postmortem glycolysis causes the rapid production of lactic acid, resulting in a fast decline in the pH; however, the ultimate pH achieved is very similar

to that of normal muscle. The rapid pH decline causes a disruption of the muscle myofibrils, thereby decreasing the water holding capacity of the muscle. The loose muscle structure scatters the light and the meat appears pale (Walters, 1975). The storage life of PSE meat is limited because of deterioration of colour during storage (Greer and Murray, 1988). A more significant problem for storage life occurs when animals experience stress for long times prior to slaughter. During long term stress, muscle glycogen is depleted leaving little substrate for postmortem lactic acid production. The result is meat with a higher than normal pH (> 6.0). This meat is referred to as DFD meat, and because of its dark colour, it is not appealing to consumers. The muscle proteins of DFD meat are above their isoelectric point (Lawrie, 1991); therefore, much of the water in the muscle will be associated with the proteins. The muscle fibres are tightly packed together forming a barrier to the diffusion of oxygen and the absorption of light (Walters, 1975). DFD meat appears darker as its surface does not scatter light to the same extent as meat of lower pH. The high pH of the muscle will have a significant influence on storage life because DFD meat has little or no carbohydrate as an energy source for bacterial growth. Bacteria will catabolize amino acids early in the growth cycle, which results in the early onset of spoilage (Gill and Newton, 1978). When DFD meat is stored under vacuum, spoilage organisms such as *B. thermosphacta*, Pseudomonads and *Enterobacteriaceae* are detected in high numbers (Shay and Egan, 1986; Rousset and Renerre, 1991). If an atmosphere of 100% CO_2 is maintained, the growth of these spoilage organisms is controlled and LAB prevail (Gill and Penney, 1986; Rousset and Renerre, 1991). By storing high pH beef under CO_2 in oxygen impermeable films, the storage life of the product is comparable to that of normal pH beef (Gill and Penney, 1986).

The storage life of meat products is highly dependent on storage temperature. The maximum storage life is obtained when product is held at the minimum temperature that can be achieved without freezing the meat, approximately -1.5°C (Gill and Jones, 1992). As

the storage temperature increases above this optimum, there is a progressive decrease in storage life. Gill and Molin (1991) reported that at temperatures of 0, 2 or 5°C, the storage life is about 70, 50 or 30%, respectively, of the storage life obtained at the optimum storage temperature. The decrease in storage life as temperature increases is a result of more rapid microbial growth, but it is also a result of changes in the types of microorganisms that grow. It has been demonstrated that when vacuum packaged meat is stored at ambient temperatures, *Clostridium* spp. may grow causing rapid spoilage of the product (Hauschild et al., 1985). As storage temperatures increase above 5 to 7°C, growth of *Enterobacteriaceae* will increase, reducing the time until spoilage is detected. Higher storage temperatures will increase the chances that pathogenic *Enterobacteriaceae* such as *E. coli* O157:H7 will grow, thereby compromising the safety of these products (Gill et al., 1998). In recent years, the presence of enterohemorrhagic *E. coli* in ground beef has caused foodborne illness resulting in fatality. Control of storage temperature is extremely important to reduce spoilage and to reduce the risk of growth of foodborne pathogens.

The storage atmosphere has an extremely important influence on the storage life of ground beef. By manipulating the storage atmosphere used for ground beef packaging, a meat processor can extend the storage life from "days of storage" to "weeks of storage". The extension in storage life is due to differences in the bacteriology of meat stored in different atmospheres. Dainty et al. (1983) demonstrated that the microflora that develops during storage is mainly controlled by the storage conditions. When stored aerobically at refrigeration temperature, meat generally develops a spoilage microflora of putrefactive aerobic organisms, including *Pseudomonas* spp. (Ingram, 1962; Gill and Newton, 1978; Dainty and Mackey, 1992; Gill and Greer, 1993). However, when meat is stored in either a vacuum or elevated levels of carbon dioxide, the microflora that develops mainly consists of lactic acid bacteria (Enfors et al., 1979; Dainty et al., 1983; Seideman and Durland,

1983). This change in the dominant microflora from putrefactive aerobic bacteria to lactic acid bacteria results in the extension of product storage life. The microflora of aerobically and anaerobically packaged ground beef and its impact on spoilage processes and storage life will be discussed further.

Spoilage of Aerobically Packaged Ground Beef

Aerobically stored ground beef has a relatively short storage life that is dependent on the storage temperature and the initial microbial contamination (Sutherland et al., 1975). At refrigeration temperatures, *Pseudomonas* spp. have a rapid growth rate that allows them to dominate the microbial flora. This will result in a product with a storage life of only a few days (Gill and Molin, 1991; Pierson et al., 1970). *Pseudomonas* spp. and other gram negative spoilage microorganisms found on aerobically stored meats preferentially use glucose as a carbon source; however, when glucose is depleted, the organisms begin to attack free amino acids resulting in the formation of sulphides, amines and esters (Dainty et al., 1985; Dainty et al., 1989). The putrid odours and flavours that result from these by-products indicate the onset of aerobic spoilage.

Although the aerobic spoilage microflora of ground beef stored at chill temperatures is generally dominated by the *Pseudomonas* spp., other bacteria may also be present. *Acinetobacter* spp., like the *Pseudomonas* spp., are strictly aerobic. However, *Acinetobacter* spp. do not produce the highly offensive by-products that are associated with the degradation of amino acids by *Pseudomonas* spp. (Gill and Greer, 1993). *Moraxella* spp. are another group of strict aerobes that may also be among the spoilage flora of aerobically stored ground beef (Ingram and Dainty, 1971). Like *Acinetobacter* spp., these organisms do not produce highly offensive metabolic by-products (Gill and Greer, 1993).

Thus, the *Acinetobacter-Moraxella* group of bacteria have a low spoilage potential in aerobically stored ground beef.

The *Enterobacteriaceae* may also cause spoilage in aerobically stored ground beef by metabolizing amino acids after glucose depletion. Psychrotrophic *Enterobacteriaceae* commonly associated with chilled meat include *Serratia*, *Hafnia* and *Enterobacter* spp. (Gill and Greer, 1993). Ridell and Korkeala (1997) conducted a study to determine the minimum growth temperatures of *Enterobacteriaceae* in refrigerated raw meats including minced meat, vacuum packaged meat and whole carcasses. The animal species for the samples were not indicated in the published article. *Enterobacteriaceae* were detected in all the refrigerated samples studied (Ridell and Korkeala, 1997). A total of 17 species of *Enterobacteriaceae* were identified with *Hafnia alvei* and *Serratia liquefaciens* the most frequently isolated species. The mean minimum growth temperatures of *H. alvei* and *S. liquefaciens* isolates were 2.6°C and 1.7°C, respectively (Ridell and Korkeala, 1997). *Enterobacteriaceae*, being facultative anaerobes, have a slower growth rate under aerobic conditions compared with *Pseudomonas* spp. *Enterobacteriaceae* do not grow well at low temperatures and thus will not contribute significantly to the spoilage of aerobically stored ground beef under refrigeration. The higher growth rate of the *Pseudomonas* spp. allow them to outgrow the *Enterobacteriaceae* under refrigerated, aerobic conditions. Storage temperatures above 5°C will allow the growth (Enfors et al., 1979; Blickstad and Molin, 1983), and subsequent spoilage of ground beef by the *Enterobacteriaceae*.

Brochothrix thermosphacta is a psychrotrophic, facultative anaerobe that may be found in high numbers on refrigerated, aerobically stored meat (Dainty et al., 1983). Dainty and Hibbard (1980) demonstrated that *B. thermosphacta* produces acetonin and acetic, isobutyric and isovaleric acids as major end products of metabolism on meat. These

compounds are responsible for the characteristic odour of aerobically packaged meat that has spoiled due to the growth of *B thermosphacta*. The characteristic odour has been described as dairy or cheesy (Borch et al., 1996; Mattila-Sandholm and Skytta, 1991; Gardner, 1980). *B. thermosphacta* utilizes both glucose and glutamate as energy sources but because of its slow growth rate, is a poor competitor with *Pseudomonas* spp. in aerobically stored ground beef (Jay, 1992).

Bacillus spp. are gram positive, sporeforming aerobes and are among the most widely distributed microorganisms in nature. Although most are mesophiles, and therefore not a concern in the spoilage of ground beef, psychrotrophic *Bacillus* spp. do exist (Jay, 1992; Rowan and Anderson, 1998) and they have been isolated from beef stored under aerobic conditions (Gill and Badoni, 1997). The impact of *Bacillus* spp. on the spoilage and safety of ground beef products has not been described in the scientific literature to date. However, as the meat industry implements carcass pasteurization as a microbial intervention step in the carcass dressing process, psychrotrophic *Bacillus* spp. may play a greater role in the microflora of fresh meat.

Other bacteria that have been associated with ground beef include *Micrococcus* and *Aeromonas* spp. *Micrococcus* spp. are mesophilic and should not contribute to the spoilage of refrigerated ground beef. Psychrotrophic *Aeromonas* spp. may be found in ground beef (Singh, 1998), but their impact on the spoilage of ground beef is not known.

The storage life of aerobically packaged ground beef is limited by organisms that can grow rapidly at refrigeration temperatures. The onset of spoilage of ground beef can be delayed by reducing storage temperatures to slow the growth rates of these organisms and thereby extend the time until spoilage is detected.

Microbiology of Anaerobically Packaged Fresh Meat

Vacuum packaging has been introduced as an effective method of extending the storage life of ground beef. Pierson et al. (1970) conducted a study on sensory changes in aerobically and anaerobically packaged beef. Sensory evaluation indicated that there was little difference between fresh beef and anaerobically packaged beef stored for a period of at least ten days. However, aerobically packaged beef was unacceptable after four days of storage. Recently, Worobo et al. (1997) reported that vacuum packaged ground beef could have a storage life of 20 days at 4°C. In a study of ground beef packaging, Shoup and Oblinger (1976) showed that vacuum packaged meat prepared in a central facility had a lower microbial load than ground beef prepared in the retail marketplace. A low microbial load can be achieved by limiting contamination during product handling in the retail marketplace. The storage life of vacuum packaged meats will be highly dependent on the initial microbial load as well as the type of packaging materials and the storage temperature.

After fresh meat is vacuum packaged, continued respiratory activity of meat tissues dramatically reduces the oxygen content in the package, while the carbon dioxide tension increases (Dainty and Mackey, 1992). As carbon dioxide accumulates in the package, the growth of aerobic spoilage organisms, such as *Pseudomonas* spp., is inhibited. The mechanism of carbon dioxide inhibition of gram negative organisms is unclear, however the overall effect is an increase in both the lag phase and the generation time of spoilage microorganisms (Daniels et al., 1985). Daniels et al. (1985) reviewed the mechanisms by which carbon dioxide might inhibit bacterial growth. Intracellular pH changes due to the formation of carbonic acid (Daniels et al., 1985) interfere with cellular membrane and enzyme function and plays a role in the inhibitory action of carbon dioxide on gram negative organisms (King and Nagel, 1975; Tan and Gill, 1982).

The use of packaging films that are impermeable to gas or that have very low oxygen transmission rates will extend the storage life of packaged meats. Both Newton and Rigg (1979) and Borch et al. (1996) demonstrated that the storage life of vacuum packaged meat was inversely related to the gas permeability of the packaging film. Newton and Rigg (1979) also showed that growth rates and final counts of both *Pseudomonas* spp. and *B. thermosphacta* increased with increasing film permeability. Limiting the transmission of oxygen into a package of ground beef should help to extend storage life.

When meat is stored under refrigeration conditions in an anaerobic atmosphere, the microflora will consist primarily of lactic acid bacteria (LAB). Lactic acid bacteria exist as part of the normal microflora of meat, and under anaerobic storage conditions, they will grow to high numbers and become the dominant organisms. Unlike aerobic, gram negative spoilage organisms, lactic acid bacteria do not cause spoilage until sometime after maximum population has been reached (Gill and Newton, 1978). A competitive LAB microflora acts to inhibit the growth of potent spoilage bacteria in anaerobically packaged meat.

The lactic acid bacteria may be divided into two groups based on the end products of glucose metabolism. Those that produce lactic acid as the major or sole product of glucose fermentation are homofermentative. Those that produce lactic acid, acetic acid, carbon dioxide and ethanol from glucose are heterofermentative (Jay, 1992). Sutherland et al. (1976) demonstrated that acetic acid produced by heterofermentative LAB results in a souring of chill stored vacuum packaged beef. In vacuum packaged meat, including ground beef, homofermentative *Lactobacillus* spp. generally dominate (Pierson et al., 1970; Gardner, 1980; Hitchener et al., 1982). The lactobacilli tolerate anaerobic conditions, as well as the pH of meat (5.5-5.8). Contamination of meat with large numbers of lactobacilli can result in spoilage, such as undesirable souring (Shaw and

Harding, 1984), off-odours, slime formation, greening or gas formation (Reuter, 1980). A *Lactobacillus* strain has been shown to cause spoilage of vacuum-packaged beef stored at 5°C due to the production of sulphur compounds (Shay and Egan, 1981). Other LAB that may be found in high numbers in anaerobically stored meat include *Carnobacterium* and *Leuconostoc* spp. (Shaw and Harding, 1984; McMullen and Stiles, 1993).

The growth of LAB on anaerobically packaged meat has little effect on meat colour. However, hydrogen sulphide production by *Lactobacillus* spp. and subsequent discoloration of vacuum packaged meats has been observed (Shay and Egan, 1981). If a sulphur-producing LAB dominates the microflora of vacuum-packaged meat, the meat will turn green when exposed to oxygen due to the formation of sulphmyoglobin (Lawrie, 1991).

Several lactic acid bacteria have been shown to produce antibacterial proteins referred to as bacteriocins. Bacteriocin production has been associated with LAB from meats (Schillinger and Lücke, 1989; Hastings and Stiles, 1991), and some have a broad antimicrobial spectrum (Stiles and Hastings, 1991). Bacteriocin-producing LAB have been used successfully in a limited number of cases to limit the growth of the adventitious microbial population and extend the storage life of meat (Worobo, 1997).

Brochothrix thermosphacta may be a potent spoilage organism in anaerobically stored ground beef if strict anaerobic conditions are not maintained. McMullen and Stiles (1993) compared the microbial ecology of pork loins packaged under modified atmosphere and stored at -1, 4.4 and 10°C. Increasing the oxygen transmission rate of the packaging film from 1 to 25 ml/m^2/24h, increased the growth of *B. thermosphacta*. The film with the higher oxygen transmission rate allowed oxygen levels in the package to increase to 2 to 3% over the 9 to 10 weeks of storage at -1 or 4.4°C. Under anaerobic conditions, *B.*

thermosphacta grows primarily by utilization of glucose and produces lactic acid as the main by-product of its metabolism (Nychas et al., 1988). The organism also produces isovaleric and isobutyric acids by the metabolism of the amino acids leucine and valine (Dainty and Hibbard, 1980). These acid by-products are the odorous compounds that give *B. thermosphacta* a high spoilage potential in anaerobically stored ground beef.

Shewanella putrefaciens is another facultative anaerobe that may cause spoilage of anaerobically packaged ground beef. However, this organism does not grow below pH 6.0 and therefore only contributes to spoilage in high pH ground beef (Gill and Greer, 1993). In DFD meat, which generally has a pH greater than 6.0, the supply of simple carbohydrates is low and the utilization of amino acids occurs causing rapid spoilage of the product. In ground beef with a higher than normal pH, *Shewanella putrefaciens* may play a leading role in the spoilage of the product.

Under anaerobic conditions, *Enterobacteriaceae* may cause putrid spoilage of ground beef with a pH above 5.8. Meat with a high pH usually has a low concentration of glucose available for microbial metabolism and microorganisms such as *Enterobacteriaceae* will begin to metabolize amino acids to produce nitrogenous and sulphur containing metabolites. The production of these malodorous metabolites results in the rapid onset of spoilage of high pH meat (Gill and Greer, 1993).

An unusual form of spoilage in anaerobically packaged meat has been attributed to the growth of *Clostridium* spp. (Dainty et al., 1989; Kalchayanand et al., 1989). Until recently, *Clostridium* spp. were not considered to be important in the spoilage of ground meat. *C. laramie* is a psychrotrophic organism that produces both hydrogen and carbon dioxide which results in distension of anaerobic packages (Dainty et al., 1989). Off-odours are attributed to the formation of a number of compounds including butanol, butanoic acid, ethanol, acetic acid and esters derived from these acids and alcohols (Dainty

and Mackey, 1992). Sulphur-containing compounds are produced that contribute to such off-odours. However, it should be noted that such spoilage is rare because most *Clostridium* spp. are mesophilic and the incidence of spores in beef is very low (Greenberg et al., 1966).

Although the microbiology of anaerobically stored fresh meat is diverse, control of initial quality, packaging conditions and storage temperature can help to limit the number of organisms that will grow and extend the storage life of the product. The meat industry has moved to using anaerobic packaging systems for distribution and storage of fresh meat to exploit the extension of storage life which occurs as a result of a shift in the microbial population from gram negative, putrefactive microorganisms to predominantly LAB.

Commercial Packaging Systems for Ground Beef

Traditionally, beef was ground and packaged in the retail store as it was required for sale. Beef trim that accumulated from preparation of the various retail cuts of beef was coarse and fine ground and packaged in the retail store. Today, ground beef prepared in the retail outlet may also include trim collected in a central facility and shipped to the retail outlet where it will be mixed with trim collected from the trimming of primal cuts and then ground and packaged for retail sale. An aerobic package consisting of a styrofoam tray with oxygen permeable overwrap is used for retail display. Ground beef prepared in the retail outlet generally has a high microbial load with microbial counts exceeding 10^6 CFU/g. In a study of the changes in the microflora of beef trimmings during collection, preparation and distribution of ground beef, Gill and McGinnis (1993) found that 75% of the ground beef samples prepared from trim and packaged for sale in the retail marketplace had a microbial count greater than 10^6 CFU/g. One factor that may contribute to such high bacterial counts is that retailers experience difficulty in dealing with fluctuating sales and

product may be stored in the retail store for extended periods of time. Inadequate hygiene in combination with extended storage and poor temperature control (James and Bailey, 1990; Greer et al., 1994) in the retail marketplace can result in products that spoil rapidly once placed on retail display. It has been demonstrated that the temperature of meat in a retail display case may exceed 10°C (Greer et al., 1994). The handling of meat in the retail outlet may result in product that has a relatively high microbial load; however, the effect of a high microbial load on consumer acceptability may be limited, depending on the source of the trim used. As was previously indicated, some trim may come from vacuum packaged primal cuts of meat that would have a high number of LAB. A high number of LAB would not necessarily contribute to spoilage (Egan and Shay, 1982). However, if the trim that is used comes from meat that was stored aerobically, the presence of large numbers of organisms would be expected to contribute to spoilage. For the purposes of this thesis, all ground beef samples prepared from trim and packaged aerobically are referred to as "in-store ground beef".

A centralized operation for ground beef can provide products for the retail marketplace with a lower microbial load than that of traditionally prepared products (Shoup and Oblinger, 1976; Emswiler et al., 1976). Centralized preparation minimizes product handling at all stages of the production chain, and perhaps, in a large central facility, there is better control over production and storage conditions than in retail outlets. There are two levels of central production in use for packaging and distribution of ground beef to the retail outlet. One is a partially centralized system that still requires grinding in the retail store and the other is a totally centralized system in which ground beef is packaged for retail sale in a central facility. For the partially centralized system, beef is coarse ground in a central facility and packaged in 10 kg cylindrical chubs using a packaging film with low oxygen permeability. This ensures that myoglobin does not become oxidized. While the chubs are not vacuum-packaged, the method used to form the chubs results in a compact cylinder of

ground beef with a low oxygen content as evidenced by the purplish myoglobin pigment (Gamage et al., 1997). The environment created in the chubs allows LAB to dominate and the growth of putrefactive gram negative spoilage bacteria is discouraged. The coarse ground beef in chub packages is shipped to retail outlets where the meat is fine ground as needed. The package used for retail display is the same as that used for ground beef prepared in the retail outlet from trim, thus the consumer cannot differentiate between the two products. Worobo et al. (1997) demonstrated that when vacuum packaged coarse ground beef produced in a central facility is stored for up to 20 days at 4°C, the resulting retail display packages can still achieve an aerobic storage life of 2.5 days, which is longer than the storage life expected for product prepared in the retail store. For the purposes of this thesis, all ground beef samples that were prepared according to a partially centralized system are referred to as "central coarse ground beef".

For preparation of ground beef by a completely centralized system, beef is coarse and fine ground in a central facility and packaged in either 454 g or 2.27 kg chubs with a packaging film of relatively high oxygen permeability. This is similar to the partially centralized handling system but in this case the meat is fine ground prior to packaging in a chub package. The chubs are shipped to retail outlets for display and sale with no further handling or packaging in the retail outlet. There is a lack of literature available regarding the bacteriological quality and storage life of ground beef prepared in this manner. However, concerns have been expressed in the news media that this product is not as "fresh" as that which is prepared in the retail outlet. For the purposes of this thesis, all ground beef samples that were fine ground and packaged in chub packages are referred to as "central fine ground beef".

Objectives of the Research

The objectives of this study were:

1. To evaluate the microbiological quality of ground beef prepared according to the three packaging systems and purchased in the retail marketplace.

2. To evaluate the sensory quality and consumer acceptability of ground beef prepared according to the three packaging systems and purchased in the retail marketplace

3. To evaluate the storage life of ground beef prepared according to the three packaging systems and stored at 4°C.

3. MATERIALS AND METHODS

Retail Sample Collection

Forty samples of lean ground beef from each of the three handling systems were purchased from the retail marketplace over a three month period. Samples were collected from 20 retail outlets on randomly chosen days. Samples were kept on ice for no more than 3 h until aliquots were removed for microbiological analysis. Each sample consisted of 3.5 to 3.8 kg of ground beef of which 1.5 kg was vacuum packaged in EVOH barrier bags (WinPak, Winnipeg, MN) with an oxygen transmission rate (OTR) of 5 ml/m^2/24 h and frozen (-18°C for 12 weeks) for trained sensory panel evaluation and approximately 2 kg was vacuum packaged in EVOH barrier bags (WinPak) and frozen (-18°C) until evaluation by a consumer panel. For a reference sample, fresh beef trim was purchased from Lilydale Foods (Edmonton, AB), and was transferred under refrigeration to the Food Processing Development Centre (Leduc, AB) where it was ground with a Vemag Robot grinder (Model 1000S; Robert Reiser & Company, Inc., Boston, MS) through a 20 mm plate (Britt Food Equip Inc., Brampton, ON) and then through a 3 mm plate (Britt Food Equip Inc.). After grinding, the ground beef for the reference samples was vacuum packaged in EVOH barrier bags (Winpak) and frozen (-18°C) until needed for evaluation.

Sample Preparation and Packaging for Storage Experiment

Fresh beef trim (85% lean) was purchased from XL Foods Ltd., Calgary, Alberta, transported to the Food Processing Development Centre in Leduc, Alberta and frozen (-20°C) in portions of 13 or 26 kg. When required, trim was removed from frozen

storage, thawed at 4°C, ground (as described above) and packaged. For in-store ground samples, ground beef was placed on a styrofoam tray, overwrapped with Resinite™ all purpose plastic food wrap (Borden Packaging and Industrial Products, Loveland, OH) and stored at 4°C for 0, 1, 2 and 3 days. For central coarse ground samples, beef trim was ground with a 20 mm plate (Britt Food Equip Inc.) and 4.5 kg were pulled into each chub package (EVOH barrier shrink bags; OTR 30 to 50 ml/m^2/24 h; Cryovac, Edmonton, AB) with a vacuum and packages were sealed with metal clips. The chub packages were stored at 4°C for 0, 1, 2 and 3 weeks. At each weekly storage interval, chubs were removed from storage and fine ground, placed on styrofoam trays, overwrapped with Resinite™ all purpose plastic food wrap (Borden Packaging and Industrial Products) and stored at 4°C for 0, 1, 2 and 3 days. For central fine ground beef samples, beef trim was coarse and fine ground (as described above) and packaged in 500 g chub packages (printed polyethylene bags; Discovery Paper, Edmonton, AB) with an oxygen transmission rate of 4000 to 5000 ml/m^2/24 h, and stored at 4°C for 0, 1, 2 and 3 weeks. The packaging process was the same as described for the central coarse ground samples. At each sample evaluation time, stored samples were vacuum packaged in EVOH barrier bags (Winpak) and frozen (-18°C) for consumer panel evaluation at a later date. The experiment was replicated three times.

Microbiological Sampling

A 10 g portion of each sample was aseptically removed and placed in a sterile stomacher bag. The sample was diluted with 90 ml of sterile 0.1% peptone water and homogenized for 1 min using a Colworth 400 Stomacher (Seward and Co., London, England). Ten-fold serial dilutions were prepared using sterile 0.1% peptone water. Appropriate dilutions were plated (0.1 ml) on prepoured plates of Plate Count Agar (PCA;

Difco Laboratories, Inc., Detroit, MI) to determine the total aerobic plate count, All Purpose Tween Agar (APT; Difco) to determine the presumptive lactic acid bacteria count, and Violet Red Bile Agar (VRBA; Difco) to determine presumptive coliform counts. PCA plates were incubated aerobically at 25°C for 2 days. APT plates were incubated anaerobically in an atmosphere of 10% CO_2 and 90% N_2 at 25°C and enumerated after 2 and 5 days of incubation. VRBA plates were overlayered with freshly prepared VRBA and incubated at 37°C for 24 hours.

Samples prepared for the storage experiment were also plated onto streptomycin thallous acetate actidione agar (STAA; Gardner, 1966) and cephaloridine, fusidic acid, cetrimide agar (CFC; Mead and Adams, 1977) to determine presumptive counts of *Brochothrix thermosphacta* and *Pseudomonas* spp., respectively. To enumerate low numbers of *B. thermosphacta*, pour plates were prepared. CFC and STAA plates were incubated aerobically at 25°C for 48 hours.

Characterization of Dominant Microflora on Retail Samples

For each of the retail samples, 10 colonies were picked for identification to the genus level. Of the 10 colonies, 5 were chosen from the highest dilution at which bacteria grew on PCA and 5 were chosen from the highest dilution at which bacteria grew on APT. When possible, care was taken to ensure colonies of different morphology were selected for characterization. The selected colonies were inoculated into APT broth (Difco) and incubated for 2 to 3 days at 25°C. To ensure purity, cultures were streaked onto the type of media from which they were originally isolated (PCA or APT). The cultures were differentiated by gram stain, catalase and oxidase reactions. Gram positive, catalase-

negative strains were inoculated into soft APT agar (0.5% agar; Difco) for short term storage at 4°C, and were subcultured twice in APT broth prior to analysis. Figure 3.1 shows the scheme used for the differentiation of the gram positive, catalase-negative organisms (LAB). Gram positive and gram negative, catalase-positive organisms were characterized according to the criteria in Tables 3.1 and 3.2, respectively. Motility was tested in Motility Medium (Difco) incubated at 25°C. Oxidative/fermentative utilization of glucose was done using OF medium (Difco) containing 1% filter-sterilized glucose. Each strain was inoculated into 2 test tubes and one tube was overlayered with approximately 2 ml of sterile mineral oil. For gram positive organisms, the ability to grow on STAA when incubated aerobically at 25°C was determined and presumptive *Bacillus* spp. were grown in *Bacillus* sporulation medium (Young and Fitz-James, 1959) and observed microscopically for spore formation. Gram negative organisms were tested for their ability to grow on CFC medium incubated aerobically at 25°C. The gram positive, catalase-negative organisms were subdivided according to the scheme proposed by Schillinger and Lücke (1987) with the exception that heterofermentative lactobacilli were differentiated from carnobacteria by their ability to grow on acetate agar (Rogosa et al., 1951).

Gas production from glucose and production of ammonia from arginine were done according to methods described by Shaw and Harding (1985). To determine the proportion of D- and L- lactate formed, strains were grown in BM broth (Wilkinson and Jones, 1977) for 48 h, heated at 80°C for 15 min, cooled, centrifuged at 14,900 x *g* for 5 min and the supernatant was analyzed for D(-)- (Gawehn, 1984), and L(+)-lactate (Noll, 1984) using D- and L-lactate dehydrogenase, NAD and glutamate pyruvate transaminase (Boehringer Mannheim, Montreal, Que.).

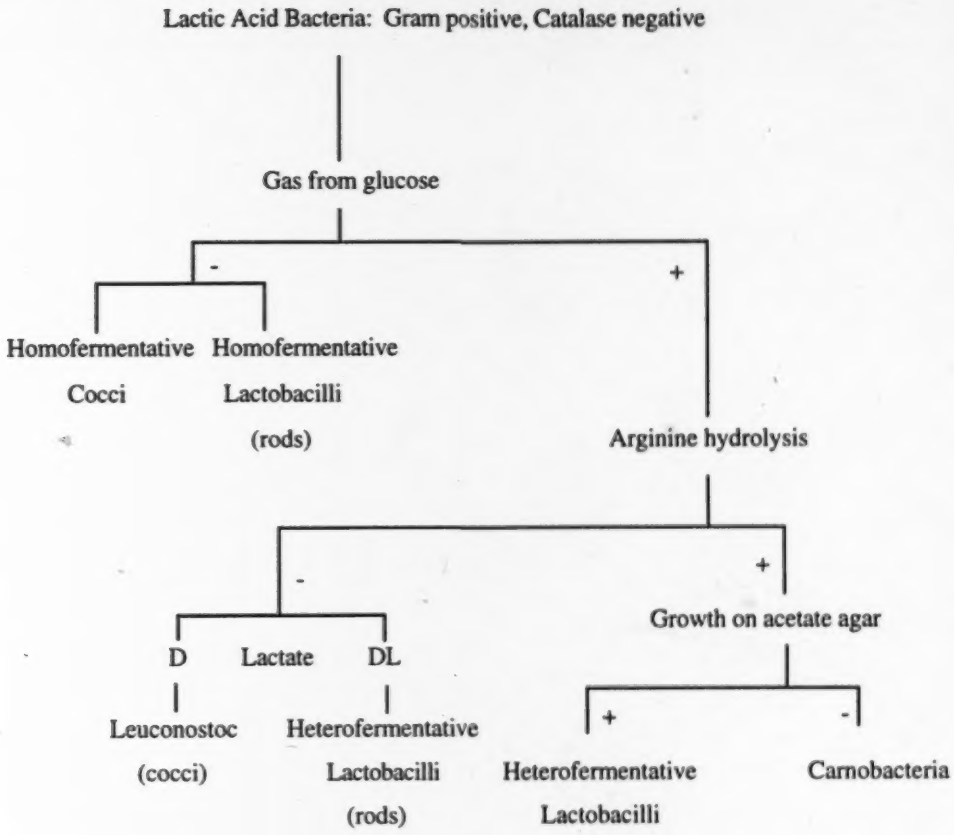

Figure 3.1. Scheme used for the differentiation of lactic acid bacteria, adapted from Schillinger and Lücke (1987).

Table 3.1. Tests used to differentiate gram positive, catalase-positive species of bacteria.[a]

Bacterial genus or species	Oxidase	Motility	Growth on STAA[b]
B. thermosphacta	-	-	+
Listeria spp.	-	+	-
Kurthia spp.	+	+	-
Bacillus spp.[c]	+/-	+	-
Micrococcus spp.	-	-	-

[a] Based on Bergey's Manual of Systematic Bacteriology (Krieg and Holt, 1986).

[b] Streptomycin sulphate thallous acetate actidione agar (Gardner, 1966) for selection of *B. thermosphacta.*

[c] Confirmed by production of spores (Young and Fitz-James, 1959)

Table 3.2. Tests used to classify gram negative, catalase-positive bacteria to the generic or Family level.[a]

Genus or Family	Oxidase	Motility	Fermentation of glucose[b]
Pseudomonas	+/-	+	O
Flavobacterium	+	-	O
Moraxella	+	-	NS
Alcaligenes	+	+	NS
Acinetobacter	-	-	NS
Shewanella	+	+	O
Aeromonas	+	+	O/F
Enterobacteriaceae	-	+/-	O/F

[a] Based on Bergey's Manual of Systematic Bacteriology (Krieg and Holt, 1986).
[b] O, oxidative; NS, nonsaccharolytic; O/F, oxidative and fermentative.

Sensory Training and Sample Presentation

The panel was screened and trained according to the procedures of the American Meat Science Association (1995). Alberta Government employees participated in a screening process using a series of 12 triangle tests to assess sensory acuity. For training, ground beef samples were modified to have different intensities of odour and flavour characteristics. These characteristics included painty, liver, sour, bitter, dairy, astringent and metallic flavours. These modified samples were given to panelists as reference samples for evaluation of the different odour and flavour characteristics. Rancid canola oil was added to fresh ground beef to prepare a reference sample with a painty flavour. The Schaal oven accelerated storage test (Joyner and McIntyre, 1938) was used to prepare the rancid oil (65°C for 12 days). Different concentrations of a cooked liver slurry (1500 g liver cooked in 1 l of water) were added to fresh ground beef to prepare samples with different intensities of liver flavour. Citric acid or caffeine were added at different concentrations to prepare samples with different intensities of sour or bitter flavours, respectively. Samples with different intensities of dairy flavour were prepared by adding different concentrations of melted butter to fresh ground beef. A 0.18% alum solution was used as a reference for an astringent flavour. To prepare a solution with a metallic flavour, a penny was boiled in water for 10 min. Twelve panelists were selected for training on the basis of their ability to correctly identify the modified samples, as well as their interest and availability.

Training sessions were held 3 to 4 times a week for 6 weeks. The first training session introduced panelists to sensory evaluation and acquainted them with the evaluation procedure. The remainder of the training sessions helped the panelists to learn to identify the different sensory characteristics present in ground beef and to teach panelists how to

scale these characteristics on a 15 cm unstructured line scale. During training, samples were also used to demonstrate differences in raw ground beef odour and appearance.

The trained panel evaluated selected retail samples that had previously been subjected to microbiological analysis. Twelve samples for each of the three handling systems were evaluated by the trained sensory panel resulting in evaluation of a total of 36 samples. Six samples were selected to represent a high total aerobic plate count and six were selected to represent a low total aerobic plate count. The designation of "high" and of "low" varied for each handling system. All samples chosen for trained panel evaluation had $\leq 10^3$ coliforms/g. The samples that were prepared for the storage life study were also subjected to sensory evaluation by the trained panel. The trained panel evaluated these samples at each designated storage time. For all samples, the trained panel evaluated the odour and appearance of the raw samples and the odour and flavour of the cooked samples using quantitative descriptive analysis with 15 cm unstructured line scales (Meilgaard et al., 1987). Panelists also used 15 cm line scales to score the odour and flavour intensity for overall and fresh beefy intensity, stale, painty, liver, sour, bitter and dairy characteristics.

Panel sessions were conducted in a sensory panel room equipped with red lights and individual booths. Samples were coded with three digit random numbers for presentation to the trained panel. At each session, panelists were given a freshly prepared reference sample, four samples purchased from the retail marketplace or four stored samples, and a coded reference sample. The order of sample presentation was randomized. At each panel session, panelists were given ground beef reference samples for each of the characteristics previously described. Based on data obtained for samples evaluated during training sessions, the references for painty, liver, sour, bitter and dairy were anchored at 7.5 cm on the 15 cm line scale. The painty reference contained 8% rancid canola oil. The

liver reference contained 12% liver slurry solution. The sour reference contained 1.2% citric acid added as a 0.12% solution. The bitter reference contained 12% caffeine. The dairy reference was fresh ground beef with 17.5% melted butter added. A 0.18% solution of alum was used as the astringent reference and was anchored at 10 cm on the 15 cm scale. The same metallic reference solution was used during screening and training with no anchoring.

Fresh ground beef was compared with sour samples prepared by the addition of vinegar, and painty samples prepared by the addition of rancid oil. Raw ground beef samples that had been left uncovered in the refrigerator for 2 to 5 days were used for training for evaluation of appearance.

Sample Preparation

For sample preparation, frozen retail samples were removed from the freezer and thawed (24 h at 4°C). Samples from the storage life study were removed from storage and prepared immediately for evaluation. For the evaluation of the appearance of the raw, fine ground beef, 80 g of each sample was placed into individual petri dishes, covered and sealed with parafilm and refrigerated (4°C). Thirty minutes prior to evaluation by the trained panel, the lid of each petri dish was removed and the samples were exposed to air at room temperature to allow them to "bloom". Colour scaling was done using a modification of the method described by Jeremiah and Greer (1982). Category scales were replaced with 15 cm line scales. On the 15 cm scale, pale red was anchored at 4 cm, bright cherry red at 7.5 cm and extremely dark red at 14.5 cm. Discoloration standards for retail beef (Jeremiah and Greer, 1982) were used as reference points for the amount of discoloration.

For the evaluation of odour of the raw ground beef, approximately 10 g of each raw sample was placed in an individual 30 ml plastic cup with a lid. The samples were refrigerated until 15 min prior to sensory evaluation, at which time they were held at room temperature. Panelists were instructed to remove the lid from the plastic cup, and to hold the sample just under the nose and take short sniffs to smell the ground beef.

For the evaluation of the odour and flavour of the cooked samples, 700 g of fine ground beef samples were baked as loaves in glass baking dishes (23 x 13 x 8 cm) at 164°C for approximately 90 min to a final internal temperature of 90 to 95°C. Prior to evaluation, the dark brown edges of the loaves were removed and each loaf was cut into eight pieces. Each piece was ground separately in a food processor (Cuisinart DLC-7, Weil Company Ltd., Downsview, ON) for 15 s. All of the ground beef from each sample was then mixed thoroughly by hand in a large container. The ground beef was mixed for another 15 s in the food processor and 10 g samples were distributed into small glass jars, covered with foil, and refrigerated. The reference sample was mixed in the food processor for 30 s and distributed in 10 g portions in small glass jars, covered with foil and refrigerated. On each sampling day, additional samples were made from reference ground beef for preparation of odour and flavour references. Samples were heated in a water bath at 55°C for 20 min prior to panel evaluation. For flavour evaluation, panelists were given water and crackers for rinsing and cleansing the palate between samples.

For the evaluation of odour and flavour of the cooked samples by the consumer panels, approximately 1000 g of ground beef for each treatment was placed in separate 21 x 27 cm aluminium foil pans (Unisource Canada Inc., Edmonton, AB) and placed in a preheated 176°C convection oven (Bakers Pride, Model X300). Two pans were prepared for each treatment and the order of cooking was randomized. The ground beef loaves were

cooked to an internal temperature of 78°C. The internal temperature was monitored by a copper-constantan thermocouple attached to a Honeywell 250 mm Strip Chart Recorder (Model DPR 3000; Thermo-Kinetics Company Limited, Edmonton, AB) and verified with a hand-held thermometer (Barnant 90, Barnant Company, Barrington, IL). The meat loaves were cooled for 20 min at room temperature to an internal temperature of approximately 55°C. Cooked meat loaves were removed from the pan, and the edges of each meatloaf were trimmed. Each meatloaf was then cut into 2.2 x 2.2 x 1.5 cm pieces to obtain 48 pieces per pan or a total of 96 pieces per treatment. Samples were covered with Resinite™ plastic film (The Borden Co. Ltd, Barrie, ON) and stored at 4°C in glass Pyrex dishes. Prior to each consumer evaluation, samples for each treatment were placed on white paper plates (Chinet®) and warmed to 50 to 55°C for 20 s in a microwave oven (Panasonic).

pH and Colour of Ground Beef

The surface pH of the ground beef samples was determined with a Corning high performance combination pH electrode (Fisher Scientific, Ottawa, ON). Meat colour was determined using a Hunterlab tristimulus colorimeter (model D25L-9, Hunter Associates Laboratory Inc., Fairfax, VA), which measures the reflectance coordinates (L, a, b). The L coordinate represents the brightness or paleness of the meat with higher values indicating lighter colours; the a coordinate measures the red-green spectrum with higher values indicating redder meat; and the b coordinate measures the yellow-blue spectrum, with higher values indicating a more yellow colour.

Consumer Acceptance of Ground Beef

Consumer panels were done for retail samples and samples from the storage life study. Sample selection was based on the ability of the trained panel to detect differences between samples. For the retail study, one sample from each handling system was selected for consumer evaluation. The microbiological data for these samples was similar. A consumer panel of approximately 80 participants evaluated treatment samples and a freshly prepared reference sample for the acceptability of cooked odour and flavour and overall acceptability.

Two consumer panels were conducted on samples selected from the storage life study. The first consumer panel evaluated samples prepared according to the three handling systems. The in-store ground beef sample was evaluated on day 0 of aerobic storage. Samples from central coarse ground and central fine ground handling systems were evaluated after 2 weeks of storage in chub packages. A second consumer panel compared the acceptability of an in-store ground beef sample that had been stored aerobically for 3 days with the acceptability of central coarse ground samples stored in vacuum for 2 weeks and stored aerobically for 0 or 3 days.

Staff and students at the University of Alberta participated in the consumer panel. Each panelist was instructed to evaluate the samples in the order that they were listed on their scorecards. The panelists evaluated one freshly prepared sample and three samples that were previously evaluated by the trained sensory panel. The panelists were asked to evaluate the cooked odour, flavour and overall acceptability using a 9-point hedonic scale with the following scaling points: 1-dislike extremely; 2-dislike very much; 3-dislike moderately; 4-dislike slightly; 5-neither like nor dislike; 6-like slightly; 7-like moderately;

8-like very much; 9-like extremely. Water and crackers were given to the panelists for rinsing and cleansing the palate between samples.

Experimental Design and Analysis

The storage life experiment was replicated three times. Means for trained panel data for retail samples were calculated across six replicates and 12 panelists. All microbiological data were expressed as colony forming units (CFU)/g and the geometric means were calculated from the data. The microbiological and sensory data was subjected to Analysis of Variance (ANOVA) using the General Linear Model (GLM) procedure of the Statistical Analysis System (SAS Institute, 1989), and means were separated using Student-Newman-Keuls' Multiple Range test (Steele and Torrie, 1980).

4. RESULTS

QUALITY OF GROUND BEEF IN THE RETAIL MARKETPLACE

Bacterial Load of Ground Beef

The means of the total aerobic plate counts for samples from each of the three handling systems under investigation are shown in Table 4.1. Bacterial counts were highest for the in-store ground beef samples where total aerobic plate counts ranged from 10^5 to 10^8 CFU/g. Eighty-five percent of the in-store ground beef samples had a total aerobic plate count of, or exceeding 10^6 CFU/g. Of the forty in-store ground beef samples, none had a total aerobic plate count less than 10^5 CFU/g. The central coarse ground beef samples that were prepared as partially centralized product had the lowest bacterial counts and only 27.5% had a total aerobic plate count of, or exceeding 10^6 CFU/g. Comparatively, 43.9% of the central fine ground beef samples had a total aerobic plate count of, or exceeding 10^6 CFU/g. Thirty five percent of the central coarse ground samples had a total aerobic plate count of less than 10^5 CFU/g, whereas only 23% of the central fine ground beef samples had total aerobic plate counts below 10^5 CFU/g.

The in-store ground beef samples had the highest number of coliforms followed by the central coarse ground beef samples (Table 4.1). The central fine ground beef samples had the lowest number of coliforms.

Table 4.1. Mean[1] aerobic plate counts[2], lactic acid bacteria counts[3] and coliform counts[4] for ground beef samples prepared by three commercial handling systems.

Bacterial Count	Central Coarse[5]	In-Store Ground[5]	Central Fine[5]	SEM[6]
Total Aerobic Plate Count	5.36[b]	6.62[a]	5.84[c]	0.15***
Lactic Acid Bacteria (2 day)	5.32[b]	6.63[a]	5.98[c]	0.16***
Lactic Acid Bacteria (5 day)	5.84[b]	6.79[a]	6.23[b]	0.18**
Coliforms	2.70[b]	3.70[a]	2.15[c]	0.18***

1 Means are averages of bacterial counts obtained for 40 samples.

2 PCA plates were incubated aerobically at 25°C for 2 days.

3 APT plates were incubated anaerobically at 25°C and enumerated after 2 and 5 days.

4 VRBA plates were incubated aerobically at 37°C for 24 h.

5 Expressed as mean log CFU/g.

6 Standard error of the mean.

abc Means within the same row sharing a common letter are not significantly different from each other, $p<0.05$.

, * Significant at $p<0.01$ and $p<0.001$, respectively.

Characterization of Dominant Microflora on Retail Samples

The distribution of different genera of bacteria found among the dominant microflora of samples obtained for the three handling systems is shown in Figures 4.1 and 4.2. A total of 1008 organisms was characterized. Of the organisms isolated as the dominant microflora of in-store ground beef samples, 88.1% were lactic acid bacteria. In comparison, lactic acid bacteria made up 71.6 and 75.1% of the organisms isolated from the central coarse and central fine ground beef samples, respectively. Homofermentative lactobacilli dominated the microflora of ground beef samples prepared by all three handling systems.

The distribution of the catalase-positive microorganisms isolated as a part of dominant microflora of retail ground beef samples is shown in Figure 4.2. The microflora of the central coarse ground beef samples had the greatest proportion of catalase-positive organisms. The dominant microflora of these samples contained a greater proportion of *Bacillus* spp. and *B. thermosphacta* compared with the microflora of samples processed by the other two handling systems.

Sensory Evaluation of Retail Ground Beef by the Trained Panel

The trained sensory panel evaluated the appearance and odour of the raw ground beef samples prepared by the three commercial handling systems. The results in Table 4.2 show that samples from all three commercial handling systems were less red than a freshly prepared reference sample and that the in-store ground beef samples were less red than samples prepared by either of the central processing methods. The trained panel found no significant difference in the overall odour intensity of ground beef samples prepared by the three handling systems. The freshly prepared reference sample had a stronger fresh beefy

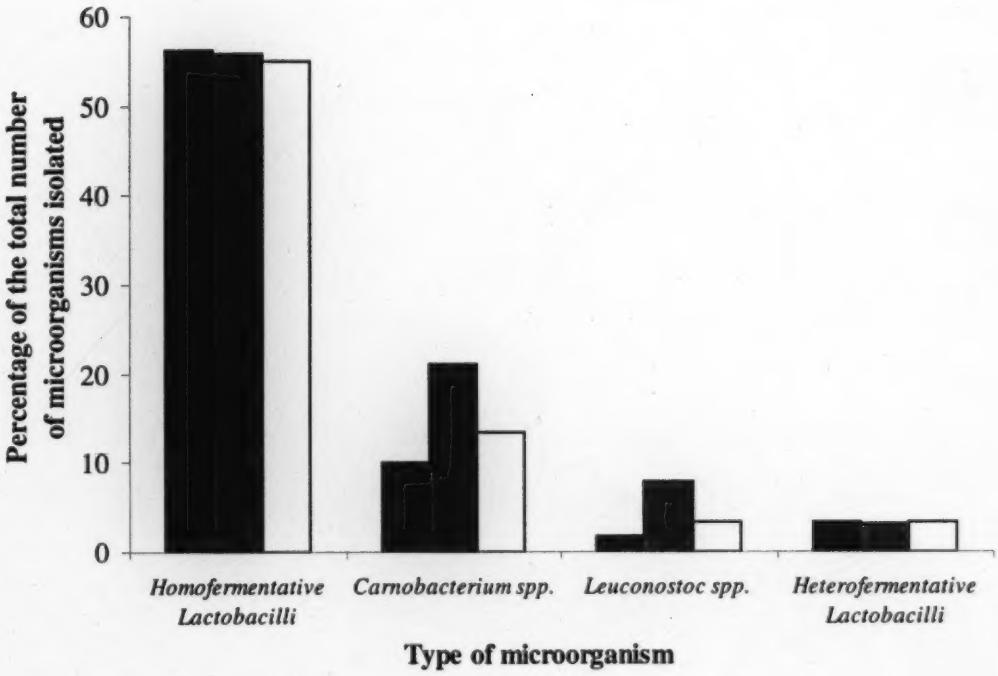

Figure 4.1. Distribution of lactic acid bacteria recovered from 120 samples of ground beef obtained from the retail marketplace packaged as central coarse (■), in-store (▣) and central fine ground beef (□).

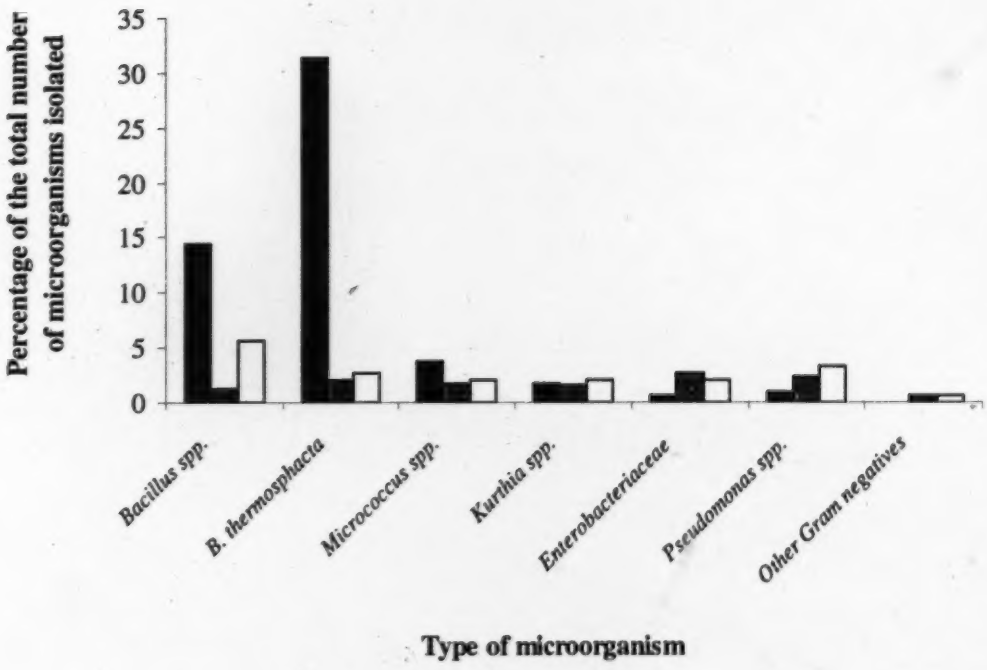

Figure 4.2. Distribution of catalase-positive, gram-negative and gram-positive organisms recovered from 120 samples of ground beef obtained from the retail marketplace packaged as central coarse (■), in-store (▩) and central fine ground beef (□).

Table 4.2. Mean[1] scores from the trained panel evaluation of the appearance and odour of a freshly prepared reference sample and ground beef samples[2] prepared according to three commercial handling systems and purchased in the retail marketplace.

		Sample				
	Attribute	**Freshly Prepared Reference**	**Central Coarse**	**In-Store Ground**	**Central Fine**	**SEM[3]**
Appearance	*Redness*	13.4[a]	10.0[b]	7.9[c]	9.9[b]	0.43***
Odour	*Overall Intensity*	6.0	7.0	6.9	6.5	0.29
	Fresh Beefy	5.0[a]	3.8[b]	2.7[c]	2.8[c]	0.22***
	Painty	0.3	0.3	0.7	0.7	0.15
	Sour	1.3[b]	2.6[a]	2.6[a]	2.3[a]	0.27*
	Dairy	0.3[b]	0.6[ab]	0.9[a]	0.7[ab]	0.12*

1 Means are averages of 144 scores (12 panelists, 12 replications).

2 Samples were evaluated using quantitative descriptive analysis with 15 cm unstructured line scales.

3 Standard error of the mean.

abc Means within the same row sharing a common letter are not significantly different from each other, $p<0.05$.

*, *** Significant at $p<0.05$ and $p<0.001$, respectively.

odour than the commercially prepared samples, and the central coarse ground samples had a significantly stronger fresh beefy odour than samples that had been prepared as in-store ground or central fine ground products. All of the ground beef samples had a very low intensity of painty odour. The freshly prepared reference sample had a less intense sour odour than the commercially prepared samples, which were not significantly different from each other. The in-store ground beef samples had a significantly more intense dairy odour than the freshly prepared reference sample; however, values for intensity of a dairy characteristic were very low for all samples.

The results for the trained panel evaluation of the odour characteristics of the cooked ground beef samples representing the three handling systems are shown in Table 4.3. For the attributes of overall odour intensity and intensity of stale, painty, liver and sour characteristics, there were no significant differences among means of the samples representing the three handling systems and the reference sample. The cooked commercially prepared samples did not differ in the intensity of the fresh beefy or dairy odour although the in-store ground and central fine ground beef samples had a less intense fresh beefy odour than the freshly prepared reference sample and the in-store ground beef samples had a stronger dairy odour than the freshly prepared reference sample.

The trained sensory panel also evaluated the cooked flavour of the ground beef samples (Table 4.4). The cooked flavour of samples prepared by all three commercial handling systems and the freshly ground reference were similar for overall, stale, liver, sour, bitter, astringent and metallic flavour characteristics. Samples representing the three commercial handling systems had a significantly less intense fresh beefy flavour than the freshly prepared reference sample. The in-store and central fine ground beef samples had a significantly more intense painty flavour than the reference sample. The commercially

Table 4.3. Mean[1] scores for the trained panel evaluation of the odour characteristics of a cooked, freshly prepared reference sample and ground beef samples[2] prepared according to three commercial handling systems and purchased in the retail marketplace.

Attribute	Sample				SEM[3]
	Freshly Prepared Reference	Central Coarse	In-Store Ground	Central Fine	
Overall Intensity	10.7	10.8	11.3	11.2	0.14
Fresh Beefy	9.5[a]	8.5[ab]	7.2[b]	7.8[b]	0.37**
Stale	0.1	0.3	0.4	0.3	0.07
Painty	0.1	0.3	0.4	0.6	0.13
Liver	0.2	0.4	0.3	0.5	0.10
Sour	0.1	0.2	0.6	0.6	0.16
Dairy	0.1[b]	0.5[ab]	1.2[a]	0.6[ab]	0.20**

1 Means are averages of 144 scores (12 panelists, 12 relications).

2 Samples were evaluated using quantitative descriptive analysis with 15 cm unstructured line scales.

3 Standard error of the mean.

ab Means within the same row sharing a common letter are not significantly different from each other, $p<0.05$.

** Significant at $p< 0.01$.

Table 4.4. Mean[1] scores for the trained panel evaluation of the flavour attributes of a cooked, freshly prepared reference sample and ground beef samples[2] prepared according to three commercial handling systems and purchased in the retail marketplace.

Attribute	Sample				SEM[3]
	Freshly Prepared Reference	Central Coarse	In-Store Ground	Central Fine	
Overall Intensity	10.6	10.4	10.9	10.8	0.14
Fresh Beefy	9.7[a]	8.1[b]	7.4[b]	7.5[b]	0.30***
Stale	0.3	0.6	0.6	0.5	0.09
Painty	0.1[b]	0.4[ab]	0.6[a]	0.8[a]	0.13**
Liver	0.2	0.4	0.3	0.4	0.07
Sour	0.7	0.6	1.0	0.8	0.16
Bitter	0.1	0.2	0.3	0.2	0.04
Dairy	0.0[b]	0.8[a]	1.1[a]	1.0[a]	0.13***
Astringent	0.0	0.0	0.0	0.0	0.01
Metallic	0.0	0.0	0.0	0.0	0.02

1 Means are averages of 144 scores (12 panelists, 12 replications).

2 Samples were evaluated using quantitative descriptive analysis with 15 cm unstructured line scales.

3 Standard error of the mean.

ab Means within the same row sharing a common letter are not significantly different from each other, $p<0.05$.

, * Significant at $p<0.01$ and $p<0.001$, respectively.

prepared samples had a significantly more intense dairy flavour than the freshly prepared reference sample.

The Colour and pH of the Retail Ground Beef Samples

The L (lightness), a (red-green) and b (yellow-blue) colour coordinates for the freshly ground reference and samples prepared by the three handling systems are shown in Table 4.5. The commercially prepared samples from the three handling systems were not significantly different from each other for any of the colour coordinates. However, the commercially prepared samples were lighter in colour and had a significantly higher b value than the freshly ground reference sample. The pH of the commercially prepared samples ranged from 5.36 to 6.28 with a mean pH of 5.8. The pH of the samples representing the three commercial handling systems was not significantly different (data not shown); however, the central coarse ground samples had a higher ($p<0.05$) pH than the freshly ground reference sample.

Consumer Acceptance of Ground Beef Purchased in the Retail Marketplace

The consumer panel consisted of 81 individuals of whom 58% were female and 42% were male. Of the consumer panelists, 53% were between the ages of 18 and 25. The consumer panel evaluated a freshly prepared reference sample and three samples selected to represent the three commercial handling systems. Table 4.6 shows the results for odour, flavour and overall acceptance of the cooked ground beef samples. All data collected from the consumer panel were normally distributed. The reference sample had a significantly more acceptable cooked odour than the commercially prepared samples. The acceptability of the odour of the central coarse ground and central fine ground samples was similar but both had a significantly less acceptable odour than the in-store ground sample.

Table 4.5. Mean[1] values for L (lightness), a (red-green) and b (yellow-blue) colour coordinates for a freshly prepared reference sample and ground beef samples prepared according to three commercial handling systems and purchased in the retail marketplace.

Colour Coordinate	Sample				SEM[2]
	Freshly Prepared Reference	Central Coarse	In-store Ground	Central Fine	
L	33.1[b]	38.5[a]	39.4[a]	37.8[a]	0.42***
a	15.7	17.5	16.3	17.7	0.63
b	9.0[b]	11.1[a]	11.2[a]	11.1[a]	0.15***

1 Mean of 12 samples

2 Standard error of the mean.

[ab] Means within the same row sharing a common letter are not significantly different from each other, $p<0.05$.

*** Significant at $p<0.001$.

Table 4.6. Mean[1] scores for the consumer evaluation of the odour, flavour and overall acceptability of meatloaf prepared from a freshly ground reference sample and ground beef prepared according to three commercial handling systems and purchased in the retail marketplace.

Attribute	Packaging Treatment				SEM[2]
	Freshly Prepared Reference	Central Coarse	In-Store Ground	Central Fine	
Odour	6.3[a]	5.3[c]	5.9[b]	5.4[c]	0.13***
Flavour	6.3[a]	5.2[b]	6.0[a]	5.1[b]	0.17***
Overall Acceptability	6.3[a]	5.2[b]	6.0[a]	5.2[b]	0.17***

[1] Mean of 81 panelists, scores of 9 and 1 correspond to like extremely and dislike extremely, respectively.

[2] Standard error of the mean.

[abc] Means within the same row sharing a common letter are not significantly different from each other, $p<0.05$.

*** Significant at $p<0.001$.

The reference sample and the in-store ground beef sample were similar in flavour acceptability. The central coarse ground and central fine ground samples had a significantly less acceptable flavour than either the reference or the in-store ground beef sample. The consumer panel found the reference and the in-store ground samples to be significantly more acceptable overall than the central coarse and central fine ground beef samples.

STORAGE LIFE OF GROUND BEEF

Storage Life of In-Store Ground Beef

Bacteriology, pH and Colour

Changes in the mean bacterial counts over the three day aerobic storage period are shown in Figure 4.3. Results of the statistical analysis indicated that there were no significant differences in total aerobic plate count, lactic acid bacteria or *Pseudomonas* spp. over the three days of aerobic storage. There was a small increase ($p<0.05$) in the numbers of *B. thermosphacta* after two days of aerobic storage but *B. thermosphacta* counts for samples stored for 3 days were not significantly different than those stored for 0, 1, or 2 days.

The initial mean pH of the in-store ground beef samples was 5.7 (data not shown) and did not change significantly over the three day aerobic storage period. After 3 days of aerobic storage the mean pH was 5.8.

The values for the L (lightness), a (red-green) and b (yellow-blue) colour coordinates are shown in Table 4.7. At no point during aerobic storage did the lightness of the stored samples differ significantly from that of the fresh reference samples. However,

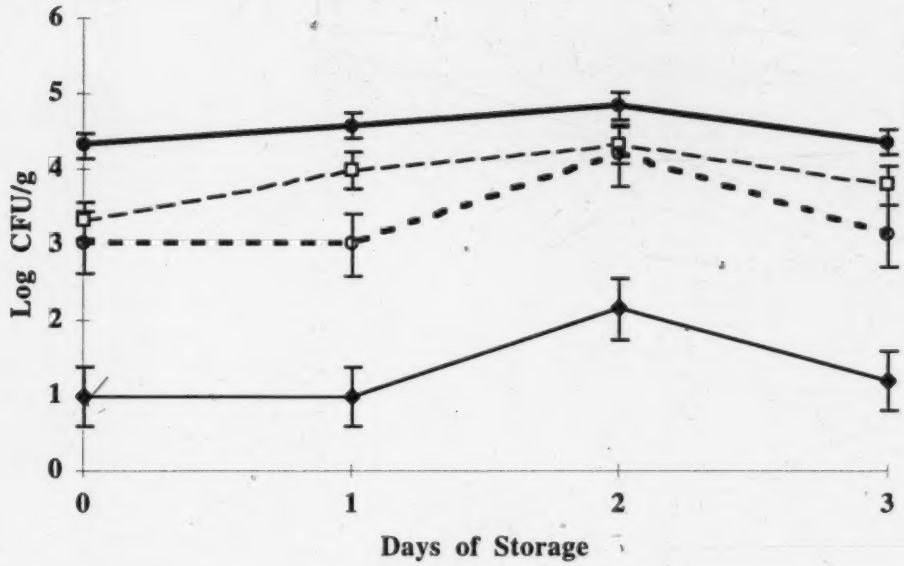

Figure 4.3. Changes in mean log counts of bacteria in in-store ground beef samples during three days of aerobic storage at 4°C. Data points are means of three samples, one sample from each of three replicates. Error bars represent standard errors of the mean log counts.

● Total aerobic colony count determined on plate count agar at 25°C;

□ Numbers of presumptive lactic acid bacteria determined on APT agar at 25°C;

○ Numbers of presumptive *Pseudomonas* spp. determined on cefaloridine fusidic acid cetrimide agar;

♦ Numbers of presumptive *Brochothrix thermosphacta* determined on streptomycin sulphate thallous acetate actidione agar.

Table 4.7. Mean[1] values for L (lightness), a (red-green) and b (yellow-blue) colour coordinates for a freshly prepared reference sample and in-store ground beef samples stored at 4°C aerobically for up to 3 days.

Colour Coordinate	Freshly Prepared Reference	Days of Storage				SEM[2]
		0	1	2	3	
L	33.4^{ab}	35.2^{a}	31.9^{b}	35.1^{a}	35.2^{a}	0.46**
a	17.3^{ab}	19.6^{a}	15.6^{b}	17.3^{ab}	17.9^{ab}	0.81*
b	9.9^{b}	11.0^{a}	8.6^{c}	10.2^{ab}	10.6^{ab}	0.21***

1 Mean of 12 scores (3 replications, 4 readings)

2 Standard error of the mean.

abc Means within the same row sharing a common letter are not significantly different from each other, $p<0.05$.

*,**, *** Significant at $p<0.05$, $p<0.01$ and $p<0.001$, respectively.

after one day of aerobic storage, the samples were paler than samples tested on other days of storage. The redness of the samples (a coordinate) did not differ significantly from the fresh reference over the storage period but samples stored for one day of aerobic storage were significantly less red than samples stored for 0 days. Samples stored aerobically for one day also had a significantly less yellow colour (lower b value) than at any other time during storage.

Trained Panel Evaluation of In-Store Ground Beef

The data presented in Table 4.8 are means for the trained panel evaluation of the redness and odour of the raw in-store ground beef samples. Samples stored aerobically for 1 day had a more intense red colour than the freshly prepared reference sample and samples stored for 0, 2 or 3 days. There were no significant differences in the intensity of most of the odour attributes of the raw, in-store ground beef samples evaluated over the three day aerobic storage period.

The results for the trained sensory panel evaluation of the odour of cooked in-store ground beef samples are shown in Table 4.9. For all of the odour attributes evaluated, there were no significant differences among samples over 3 days of aerobic storage. Table 4.10 shows the results obtained from the trained panel for the evaluation of the flavour of the cooked in-store ground beef samples. The overall flavour intensity of the in-store ground beef samples did not change over the three days of aerobic storage at 4°C and at all storage times the overall flavour intensity was not significantly different from that of the freshly prepared reference sample. The intensity of fresh beefy flavour decreased with storage time and samples stored for 2 or 3 days had a significantly less intense fresh beefy flavour than the freshly prepared reference sample. There were no significant changes in

Table 4.8. Mean[1] scores for the trained panel evaluation of the redness and odour of a raw, freshly prepared reference sample and raw, in-store ground beef samples[2] stored at 4°C aerobically for up to 3 days.

	Attribute	Freshly Prepared Reference	Days of Storage 0	1	2	3	SEM[3]
Appearance	*Redness*	11.5[b]	10.9[b]	13.7[a]	11.1[b]	10.4[b]	0.49*
Odour	*Overall Intensity*	5.6	5.6	6.1	6.4	6.0	0.28
	Fresh Beefy	4.5	4.3	4.0	4.0	4.2	0.13
	Painty	0.3	0.2	0.9	0.7	0.6	0.29
	Sour	0.6	0.6	0.7	0.9	0.5	0.14
	Dairy	0.2[b]	0.3[ab]	0.5[ab]	0.4[ab]	0.6[a]	0.08*

[1] Means are averages of 36 scores (12 panelists, 3 replications).

[2] Samples were evaluated using quantitative descriptive analysis with 15 cm unstructured line scales.

[3] Standard error of the mean.

[ab] Means within the same row sharing a common letter are not significantly different from each other, $p<0.05$.

* Significant at $p<0.05$.

Table 4.9. Mean[1] scores for the trained panel evaluation of the odour of a cooked, freshly prepared reference sample and cooked, in-store ground beef samples[2] stored at 4°C aerobically for up to 3 days.

Attribute	Freshly Prepared Reference	Days of Storage				SEM[3]
		0	1	2	3	
Overall Intensity	11.0	11.0	11.0	11.1	11.1	0.11
Fresh Beefy	9.4	9.1	9.2	9.0	9.2	0.25
Stale	0.1	0.2	0.1	0.2	0.2	0.09
Painty	0.1	0.1	0.2	0.4	0.3	0.15
Liver	0.1	0.2	0.4	0.2	0.2	0.11
Sour	0.1	0.1	0.1	0.2	0.1	0.04
Dairy	0.4	0.4	0.1	0.5	0.6	0.15

[1] Means are averages of 36 scores (12 panelists, 3 replications).

[2] Samples were evaluated using quantitative descriptive analysis with 15 cm unstructured line scales.

[3] Standard error of the mean.

Table 4.10. Mean[1] scores for the trained panel evaluation of the flavour of a cooked, freshly prepared reference sample and cooked, in-store ground beef samples[2] stored at 4°C aerobically for up to 3 days.

Attribute	Freshly Prepared Reference	Days of Storage 0	1	2	3	SEM[3]
Overall Intensity	11.1	10.9	10.6	10.1	10.4	0.21
Fresh Beefy	9.4[a]	9.7[a]	9.1[ab]	7.9[b]	8.2[b]	0.29**
Stale	0.1	0.2	0.4	0.8	0.5	0.16
Painty	0.2	0.1	0.2	0.4	0.5	0.10
Liver	0.1[b]	0.0[b]	0.3[a]	0.0[b]	0.1[b]	0.05*
Sour	0.7	0.6	0.6	0.4	0.5	0.09
Bitter	0.2	0.0	0.0	0.2	0.1	0.07
Dairy	0.5	0.5	0.2	0.4	0.8	0.12

1 Means are averages of 36 scores (12 panelists, 3 replications).

2 Samples were evaluated using quantitative descriptive analysis with 15 cm unstructured line scales.

3 Standard error of the mean.

ab Means within the same row sharing a common letter are not significantly different from each other, $p<0.05$.

*, ** Significant at $p<0.05$ and $p<0.01$, respectively.

the intensity of stale, painty, sour, bitter or dairy characteristics over the three days of aerobic storage. The intensity of a liver flavour increased significantly after one day of storage but the liver flavour intensity of samples stored for 2 or 3 days of storage was similar to that of the freshly prepared reference sample.

Storage Life of Central Coarse Ground Beef

Bacteriology, pH and Colour

There were no significant differences among the bacterial counts of the samples evaluated on each of the three days of storage within each week, therefore results in Figure 4.4 represent data that was pooled across days within each week. All bacterial counts increased over the 3 week storage period. The total plate count reached 10^7 CFU/g after 1 week of storage and did not increase with further storage. Numbers of total aerobic bacteria, lactic acid bacteria and *Pseudomonas* spp. did not change between 2 and 3 weeks of storage; however, counts of *B. thermosphacta* increased significantly in that time period.

The surface pH of the central coarse ground beef samples (Table 4.11) ranged between pH 6.1 and 5.6. No significant change in pH occured during the 3 days of aerobic storage at each weekly storage interval. However, as storage time in a chub package increased, the pH tended to decrease, although the decrease was not always significant.

Storage of central coarse ground beef in a chub package had little effect on the lightness (L) of the ground beef after it was fine ground and stored aerobically for 3 days (Table 4.11). However, as the storage time in the chub package increased, the central coarse ground beef stored aerobically tended to have a lighter colour, although differences

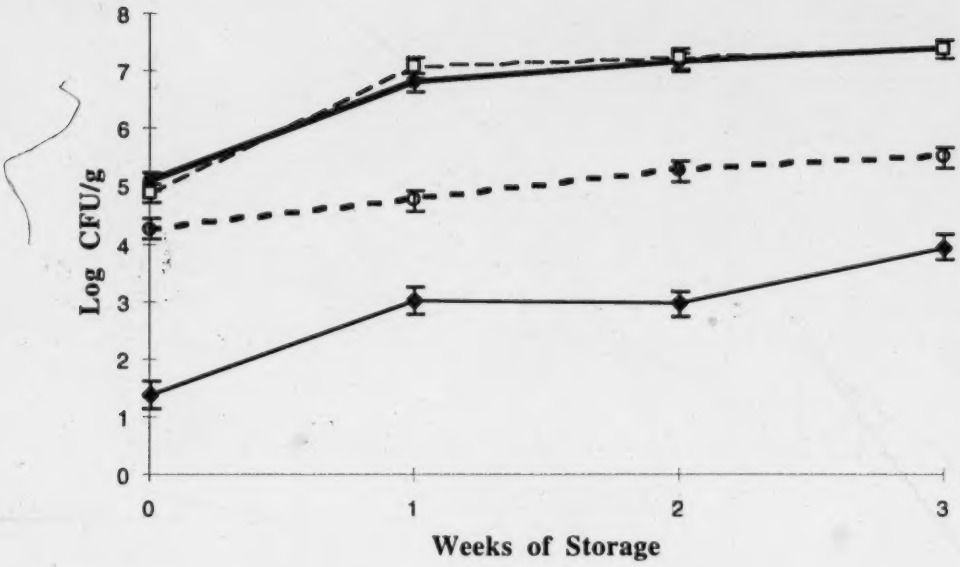

Figure 4.4. Changes in mean log counts of bacteria in central coarse ground beef samples during three weeks of storage at 4°C. Data points are means of 12 samples (3 replicates x 4 samples). Error bars represent standard errors of the mean log counts.

- ● Total aerobic colony count determined on plate count agar at 25°C;
- □ Numbers of presumptive lactic acid bacteria determined on APT agar at 25°C;
- ○ Numbers of presumptive *Pseudomonas* spp. determined on cefaloridine fusidic acid cetrimide agar;
- ♦ Numbers of presumptive *Brochothrix thermosphacta* determined on streptomycin sulphate thallous acetate actidione agar.

Table 4.11. Mean[1] values for pH, L (lightness), a (red-green) and b (yellow-blue) colour coordinates for a freshly prepared reference sample and central coarse ground beef samples stored at 4°C in a chub package for up to 3 weeks and stored aerobically for up to 3 days.

			Days of Storage				
Attribute	**Week**	**Freshly Prepared Reference**	**0**	**1**	**2**	**3**	**SEM[2]**
pH	0	5.9	5.9	6.1^{y}	6.0	6.0^{y}	0.09
	1	6.1	6.0	6.0^{y}	6.0	5.6^{z}	0.13
	2	6.0	5.7	5.8^{z}	5.7	5.6^{z}	0.10
	3	5.9	5.7	5.7^{z}	5.7	5.6^{z}	0.10
L	0	33.0	33.7	32.9^{z}	33.5	34.2^{z}	0.44
	1	32.9^{b}	33.5^{b}	33.8^{bz}	35.5^{a}	35.9^{ayz}	0.36*
	2	32.8^{b}	36.5^{a}	36.3^{ay}	35.8^{a}	36.8^{ay}	0.69*
	3	32.9^{b}	37.1^{a}	37.8^{ay}	38.2^{a}	37.7^{ay}	0.75**
a	0	16.5	15.8^{z}	17.1^{y}	16.4	15.1^{yz}	0.74
	1	17.5	17.3^{yz}	18.4^{y}	15.7	17.5^{y}	0.76
	2	17.5^{a}	20.1^{ay}	12.5^{bz}	13.1^{b}	14.4^{byz}	0.90*
	3	19.4^{a}	20.8^{ay}	10.7^{bz}	10.4^{b}	11.6^{bz}	0.50***
b	0	9.8	9.6^{z}	9.7	9.6	9.5	0.26
	1	10.0^{b}	9.9^{bz}	10.3^{ab}	10.1^{b}	10.7^{a}	0.16*
	2	10.0	11.4^{yz}	10.0	10.1	10.5	0.29
	3	10.5^{b}	12.0^{ay}	10.2^{b}	10.5^{b}	10.5^{b}	0.26**

[1] Mean of 12 scores (3 replications, 4 readings)

[2] Standard error of the mean.

[ab] Means within the same row sharing a common letter are not significantly different from each other, $p<0.05$.

[yz] Means within the same column sharing a common letter are not significantly different from each other, $p<0.05$.

*, **, *** Significant at $p<0.05$, $p<0.01$, and $p<0.001$, respectively.

were not always significant. As the length of storage time in a chub package increased, the values for redness increased at the time that the coarse ground beef was fine ground and packaged aerobically. However, the red colour was not stable during aerobic storage after 2 or 3 weeks in a chub package. At these storage times, the a values declined significantly after one day of aerobic storage. Storage of coarse ground beef in a chub package followed by aerobic storage had a variable effect on the yellowness of the samples, which at times was significant. However, there was no obvious trend associated with increasing length of storage.

Trained Panel Evaluation of Central Coarse Ground Beef

The results of the trained panel evaluation of the redness of the raw central coarse ground beef samples are presented in Table 4.12. After 0 or 1 week of storage in a chub package, the redness of the ground beef samples did not change over 3 days of aerobic storage. After 2 and 3 weeks of storage in a chub package, the redness of the samples tended to decrease during aerobic storage, although changes were not always significant. Data indicate that as samples were stored for a longer period of time in a chub package, the red colour intensity decreased at an earlier time during aerobic storage.

The trained sensory panel data for the odour of the raw central coarse ground beef samples is presented in Table 4.13. With no storage in a chub package (week 0), the overall odour intensity of the ground beef samples did not change over the three days of aerobic storage. However, after one week of storage in a chub package, the overall intensity of the odour of the aerobically packaged raw ground beef increased during the 3 days of storage. Data indicate that as samples were stored for a longer period of time in a chub package, the overall odour intensity increased at an earlier time during aerobic storage. The intensity of a fresh beefy odour did not decrease during aerobic storage after

Table 4.12. Mean[1] scores for the trained panel evaluation of the redness of a freshly prepared reference sample and central coarse ground beef samples[2] stored at 4°C in a chub package for up to 3 weeks and stored aerobically for up to 3 days.

Attribute	Week	Freshly Prepared Reference	Days of Storage				SEM[3]
			0	1	2	3	
Redness	0	12.45	11.2	11.8^{x}	11.5^{x}	11.8^{x}	0.59
	1	11.8	11.5	10.8^{x}	9.6^{xy}	8.9^{y}	0.50
	2	11.7^{a}	9.1^{a}	6.4^{by}	8.0^{abxy}	7.2^{abyz}	0.50***
	3	12.3^{a}	7.5^{a}	3.4^{bz}	6.4^{ay}	5.9^{az}	0.69***

[1] Means are averages of 36 scores (12 panelists, 3 replications)

[2] Samples were evaluated using quantitative descriptive analysis with 15 cm unstructured line scales.

[3] Standard error of the mean.

[ab] Means within the same row sharing a common letter are not significantly different from each other, $p<0.05$.

[xyz] Means within the same column sharing a common letter are not significantly different from each other, $p<0.05$.

*** Significant at $p< 0.001$.

Table 4.13. Mean[1] scores for the trained panel evaluation of the odour of a raw, freshly prepared reference sample and raw, central coarse ground beef samples[2] stored at 4°C in a chub package for up to 3 weeks and stored aerobically for up to 3 days.

Attribute	Week	Freshly Prepared Reference	Days of Storage 0	1	2	3	SEM[3]
Overall Intensity	0	5.6	6.4^{y}	6.2^{y}	6.2^{y}	6.2^{z}	0.25
	1	6.1^{b}	6.1^{by}	7.0^{aby}	6.7^{aby}	7.5^{ay}	0.22**
	2	5.9^{b}	8.5^{ax}	9.4^{ax}	9.3^{ax}	9.6^{ax}	0.40***
	3	6.1^{c}	9.0^{bx}	10.0^{ax}	10.0^{ax}	10.1^{ax}	0.18***
Fresh Beefy	0	4.5	4.0^{x}	4.5^{x}	4.4^{x}	4.5^{x}	0.23
	1	4.7^{a}	4.8^{ax}	3.6^{bx}	3.7^{bx}	3.1^{by}	0.27**
	2	4.6	1.5^{y}	1.3^{y}	1.3^{y}	1.1^{z}	0.33***
	3	4.7^{a}	1.4^{by}	0.9^{bcy}	0.7^{cy}	0.9^{bcz}	0.14***
Painty	0	0.4	0.5	0.4	0.5	0.5	0.13
	1	0.3	0.2	0.4	0.6	0.4	0.09
	2	0.3	0.5	0.4	0.5	0.6	0.16
	3	0.5	0.6	0.6	0.7	0.4	0.26
Sour	0	0.5	1.2^{y}	0.7^{y}	0.7^{y}	0.9^{y}	0.24
	1	0.7^{b}	0.7^{by}	2.0^{aby}	1.6^{aby}	2.4^{axy}	0.34*
	2	0.7^{b}	4.1^{ax}	4.4^{ax}	4.4^{ax}	4.8^{ax}	0.63**
	3	0.5^{b}	4.3^{ax}	4.9^{ax}	4.7^{ax}	5.1^{ax}	0.43***
Dairy	0	0.3^{b}	0.6^{ay}	0.5^{az}	0.4^{ay}	0.5^{ay}	0.04*
	1	0.4	0.4^{y}	1.3^{z}	0.7^{y}	1.7^{y}	0.40
	2	0.3^{b}	2.1^{ax}	2.9^{ay}	3.3^{ax}	3.8^{ax}	0.46**
	3	0.5^{c}	2.5^{bx}	4.2^{ax}	4.9^{ax}	4.8^{ax}	0.24***

1 Means are averages of 36 scores (12 panelists, 3 replications).

2 Samples were evaluated using quantitative descriptive analysis with 15 cm unstructured line scales.

3 Standard error of the mean.

abc Means within the same row sharing a common letter are not significantly different from each other, $p<0.05$.

xyz Means within the same column sharing a common letter are not significantly different from each other, $p<0.05$.

*, **, *** Significant at $p<0.05$, $p<0.01$ and $p<0.001$, respectively.

0 weeks of storage in a chub package. However, after one week of storage in a chub package, the intensity of the beefy odour decreased ($p<0.01$) after 2 days of aerobic storage. After 2 or 3 weeks of storage in a chub package, the fresh beefy odour of the aerobically packaged samples decreased significantly after one day of aerobic storage.

The intensity of a painty characteristic in the central coarse ground beef samples remained low and did not increase significantly during storage. After 1 week of storage, the intensity of a sour odour characteristic increased over the three days of aerobic storage. After 2 weeks of storage in a chub package panelists detected a sour odour when samples were fine ground; however, the intensity of a sour characteristic did not increase with longer periods of aerobic storage.

The intensity of a dairy odour characteristic did not increase during aerobic storage of samples that had been stored for either 0 or 1 week in a chub package. However, after 2 and 3 weeks of storage in a chub package, the intensity of a dairy odour characteristic was significantly stronger than that of the freshly prepared reference sample. After samples had been stored for 3 weeks in a chub package, the intensity of a dairy odour characteristic increased during aerobic storage.

Results for the odour characteristics of the cooked, central coarse ground beef samples are shown in Table 4.14. After 0 and 1 week of storage in a chub package, the overall odour intensity of the cooked, central coarse ground beef samples was similar to that of the freshly prepared reference and the odour of stored samples did not change over 3 days of aerobic storage. However, after 2 weeks of storage in a chub package, the overall odour intensity of the stored samples was greater than that of the freshly prepared sample and the intensity increased slightly by the third day of aerobic storage. The overall odour intensity of samples stored in a chub package for 3 weeks was significantly stronger than

Table 4.14. Mean[1] scores for the trained panel evaluation of the odour characteristics of a cooked, freshly prepared reference sample and cooked, central coarse ground beef samples[2] stored at 4°C in a chub package for up to 3 weeks and stored aerobically for up to 3 days.

Attribute	Week	Freshly Prepared Reference	Days of Storage 0	1	2	3	SEM[3]
Overall Intensity	0	11.0	11.0^{x}	10.9^{y}	10.9^{y}	10.7^{z}	0.13
	1	10.9	10.7^{x}	10.9^{y}	10.9^{y}	11.3^{y}	0.17
	2	11.0^{c}	11.6^{bwx}	12.0^{abx}	11.9^{abx}	12.4^{ax}	0.14**
	3	11.0^{c}	12.1^{bw}	13.1^{aw}	12.9^{aw}	13.0^{aw}	0.19***
Fresh Beefy	0	9.2	8.9^{w}	8.9^{w}	9.0^{w}	9.3^{w}	0.35
	1	9.8	9.3^{w}	9.1^{w}	9.6^{w}	7.8^{w}	0.50
	2	9.3^{a}	7.3^{bw}	5.5^{cx}	5.3^{cx}	4.5^{cx}	0.45***
	3	10.0^{a}	4.8^{bx}	2.5^{cy}	1.6^{cy}	2.4^{cx}	0.57***
Stale	0	0.2	0.4	0.1	0.3	0.3^{w}	0.10
	1	0.2	0.2	0.2	0.2	0.1^{x}	0.11
	2	0.1	0.1	0.2	0.1	0.1^{x}	0.01
	3	0.0	0.1	0.1	0.0	0.1^{x}	0.04
Painty	0	0.2	0.3	0.3	0.4^{wx}	0.2	0.21
	1	0.0	0.1	0.2	0.1^{x}	0.5	0.17
	2	0.0^{c}	0.5^{b}	1.1^{a}	0.7^{abwx}	0.8^{ab}	0.11**
	3	0.1	1.1	1.5	0.9^{w}	0.9	0.35
Liver	0	0.4	0.2	0.2	0.2	0.0	0.09
	1	0.1	0.1	0.2	0.2	0.3	0.36
	2	0.1	0.3	0.1	0.1	0.2	0.09
	3	0.1	0.2	0.2	0.1	0.2	0.13
Sour	0	0.1	0.1^{x}	0.3^{x}	0.2^{y}	0.1^{y}	0.14
	1	0.1	0.1^{x}	0.3^{x}	0.1^{y}	0.6^{y}	0.11
	2	0.1^{b}	0.4^{bx}	1.3^{awx}	1.6^{ax}	1.9^{ax}	0.20***
	3	0.1^{c}	1.7^{bw}	2.5^{aw}	3.0^{aw}	3.1^{aw}	0.24***
Dairy	0	0.2	0.5	0.4^{x}	0.3^{x}	0.4^{x}	0.11
	1	0.5	0.6	0.4^{x}	0.2^{x}	1.1^{x}	0.22
	2	0.5^{b}	2.0^{ab}	2.2^{abx}	2.5^{ax}	4.0^{aw}	0.44**
	3	0.3^{b}	3.3^{a}	4.7^{aw}	6.0^{aw}	5.2^{aw}	0.87*

1 Means are averages of 36 scores (12 panelists, 3 replications).

2 Samples were evaluated using quantitative descriptive analysis with 15 cm unstructured line scales.

3 Standard error of the mean.

abc Means within the same row sharing a common letter are not significantly different from each other, $p<0.05$.

wxyz Means within the same column sharing a common letter are not significantly different from each other, $p<0.05$.

*, **, *** Significant at $p<0.05$, $p<0.01$ and $p<0.001$, respectively.

that of the freshly prepared reference samples after 1 day of aerobic storage and the odour was stronger ($p<0.05$) than that of samples stored for shorter times in a chub package. The intensity of a fresh beefy odour of samples stored for 0 or 1 week in a chub package did not differ ($p<0.05$) from the fresh reference sample over the three days of aerobic storage. After 2 weeks of storage in a chub package, the fresh beefy odour of the central fine ground beef samples decreased over the three days of aerobic storage. The fresh beefy odour of the samples decreased significantly after 3 weeks of storage in a chub package.

Few significant differences were found in the intensity of stale, painty and liver odours of the cooked samples after storage in chub or aerobic packaging. The intensity of sour and dairy odours did not increase during aerobic storage after 0 or 1 week in a chub package. When storage time in a chub package was extended to 2 or 3 weeks, the intensity of sour and dairy odours increased at an earlier time during aerobic storage.

The data presented in Table 4.15 shows the results for the trained sensory panel evaluation of the flavour attributes of the cooked central coarse ground beef samples. The overall intensity of the flavour of the stored samples did not change significantly from that of the freshly prepared reference until after samples that had been stored for 2 weeks in a chub package were stored for 3 days in aerobic packaging. The overall flavour intensity of the samples stored for 3 weeks as chub packaged coarse ground beef was significantly higher than the freshly prepared reference sample at all sampling times. The intensity of the fresh beefy flavour of the samples did not decrease significantly until after one week of storage in a chub package and 3 days of aerobic storage. The fresh beefy flavour of samples stored for 3 weeks in a chub package was significantly lower than that of the freshly prepared reference sample at all sampling times. As the storage time in a chub package increased, the panelists detected a less intense beefy flavour earlier during aerobic storage. Panelists detected very few changes in the stale, painty, liver and bitter flavour

Table 4.15. Mean[1] scores for the trained panel evaluation of the flavour characteristics of a cooked, freshly prepared reference sample and cooked, central coarse ground beef samples[2] stored at 4°C in a chub package for up to 3 weeks and stored aerobically for up to 3 days.

Attribute	Week	Freshly Prepared Reference	Days of Storage 0	1	2	3	SEM[3]
Overall Intensity	0	10.8	10.7^{x}	10.9^{x}	10.6^{x}	10.5^{z}	0.09
	1	11.1^{a}	10.2^{bx}	10.9^{ax}	10.8^{ax}	11.2^{ay}	0.16*
	2	10.9^{b}	11.5^{abwx}	11.9^{abx}	11.7^{abwx}	12.3^{ax}	0.23*
	3	11.1^{b}	12.5^{aw}	13.0^{aw}	12.6^{aw}	13.0^{aw}	0.17**
Fresh Beefy	0	9.4	8.2^{w}	8.8^{w}	8.8^{w}	8.8^{w}	0.37
	1	9.7^{a}	9.0^{abw}	8.8^{abw}	8.9^{abw}	7.9^{bw}	0.36
	2	9.6^{a}	7.1^{bw}	4.9^{bwx}	4.8^{bx}	4.6^{bx}	0.56***
	3	9.9^{a}	3.5^{bx}	2.5^{bx}	2.5^{by}	2.6^{bx}	0.59**
Stale	0	0.2	0.7	0.4	0.5	0.7	0.13
	1	0.1	0.7	0.5	0.5	0.3	0.14
	2	0.0^{b}	0.3^{a}	0.3^{a}	0.2^{a}	0.2^{a}	0.01
	3	0.1	0.2	0.1	0.3	0.1	0.06
Painty	0	0.0	0.6	0.1	0.4	0.1	0.19
	1	0.0^{b}	0.0^{b}	0.1^{b}	0.1^{b}	0.3^{a}	0.03**
	2	0.0^{b}	0.2^{ab}	0.9^{a}	0.5^{ab}	0.6^{ab}	0.02*
	3	0.0^{b}	0.6^{a}	0.8^{a}	0.8^{a}	0.6^{a}	0.12*
Liver	0	0.2	0.3	0.1	0.1	0.0	0.10
	1	0.2	0.1	0.2	0.2	0.3	0.11
	2	0.0^{b}	0.4^{a}	0.3^{ab}	0.1^{ab}	0.1^{ab}	0.08*
	3	0.0	0.3	0.4	0.1	0.3	0.13
Sour	0	0.8	0.9^{x}	0.8^{x}	0.6^{x}	0.5^{y}	0.16
	1	0.7^{b}	0.6^{bx}	0.7^{bx}	0.9^{bx}	1.6^{ax}	0.15**
	2	0.9^{b}	1.8^{abx}	2.4^{awx}	2.5^{aw}	3.0^{aw}	0.34*
	3	0.7	3.3^{aw}	3.3^{aw}	3.0^{aw}	3.4^{aw}	0.23**
Bitter	0	0.1	0.2	0.1	0.2	0.1^{x}	0.09*
	1	0.2	0.0	0.1	0.1	0.1^{x}	0.07
	2	0.2	0.1	0.2	0.2	0.2^{x}	0.08
	3	0.2	0.3	0.4	0.2	0.5^{w}	0.07
Dairy	0	0.4	0.2	0.2^{x}	0.4^{x}	0.7^{y}	0.11
	1	0.3^{b}	0.2^{b}	0.4^{bx}	0.4^{bx}	1.0^{ay}	0.13*
	2	0.3^{b}	1.6^{ab}	2.0^{abx}	2.5^{ax}	3.4^{ax}	0.44*
	3	0.3^{b}	4.3^{a}	6.0^{aw}	6.2^{aw}	6.3^{aw}	0.78*

1 Means are averages of 36 scores (12 panelists, 3 replications).

2 Samples were evaluated using quantitative descriptive analysis with 15 cm unstructured line scales.

3 Standard error of the mean.

ab, wxyz Means within the same row or column sharing a common letter are not significantly different from each other, $p<0.05$.

*, **, *** Significant at $p<0.05$, $p<0.01$ and $p<0.001$, respectively.

characteristics of stored samples. However, as storage time in a chub package increased, the intensity of sour and dairy flavour characteristics increased to the point that they were significantly different from the freshly prepared reference sample after three weeks of storage in a chub package.

Storage Life of Central Fine Ground Beef

Bacteriology, pH and Colour

Changes in the mean log bacterial counts obtained for central fine ground beef samples are shown in Figure 4.5. At each sampling time, there were no significant differences between samples in the numbers of total aerobic bacteria, lactic acid bacteria, *Pseudomonas* spp. or *B. thermosphacta*.

Immediately after preparation and after 1 week of storage in a 500 g chub package, the mean pH of the central fine ground beef was 5.9, which was the same as that of the freshly ground reference sample (data not shown). After 2 weeks of storage, the mean pH of the stored samples had decreased to pH 5.5; however, the pH of samples tested after 3 weeks of storage was pH 5.7.

The L (lightness), a (red-green) and b (yellow-blue) colour coordinates for the central fine ground beef samples are presented in Table 4.16. The lightness of the samples did not change significantly over the entire storage period nor did it differ from that of the freshly prepared reference sample. The redness of the samples decreased after one week of storage but no further decrease in redness was detected. The mean b values for the stored

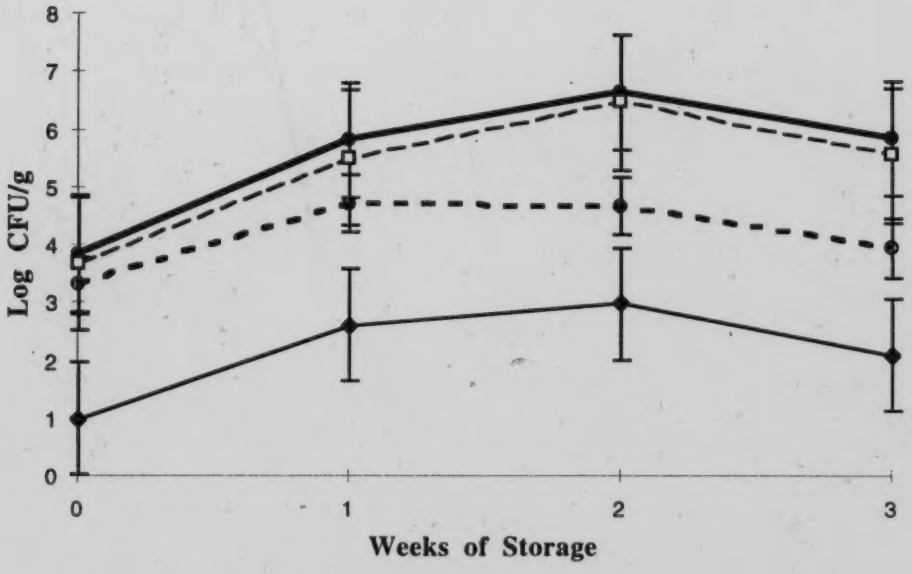

Figure 4.5. Changes in mean log counts of bacteria in central fine ground beef samples during three weeks of chub storage at 4°C. Data points are means of 3 samples, one sample from each of three replicates. Error bars represent standard errors of the mean log counts.

- ● Total aerobic colony count determined on plate count agar at 25°C;
- □ Numbers of presumptive lactic acid bacteria determined on APT agar at 25°C;
- ❍ Numbers of presumptive *Pseudomonas* spp. determined on cefaloridine fusidic acid cetrimide agar;
- ♦ Numbers of presumptive *Brochothrix thermosphacta* determined on streptomycin sulphate thallous acetate actidione agar.

Table 4.16. Mean[1] values obtained for L (lightness), a (red-green) and b (yellow-blue) colour coordinates for a freshly prepared reference sample and central fine ground beef samples stored at 4°C for up to 3 weeks.

Colour Coordinate	Freshly Prepared Reference	Weeks of Storage				SEM[2]
		0	1	2	3	
L	33.9	35.6	32.8	35.4	32.6	1.08
a	19.0^{ab}	20.6^{a}	16.9^{b}	16.3^{b}	17.4^{b}	0.78*
b	10.6^{ab}	11.4^{a}	9.6^{b}	10.6^{ab}	9.6^{b}	0.32*

[1] Mean of 12 scores (3 replications, 4 readings)

[2] Standard error of the mean.

[ab] Means within the same row sharing a common letter are not significantly different from each other, $p<0.05$.

* Significant at $p<0.05$

samples were not significantly different from that of the freshly prepared reference sample at any time during storage.

Trained Panel Evaluation of Central Fine Ground Beef

Table 4.17 shows the results obtained from the trained panel evaluation of the redness and odour characteristics of the raw, central fine ground beef samples. The amount of redness of the samples was not significantly different from that of the freshly prepared reference samples after 0, 1 or 3 weeks of storage. After 2 weeks of storage, the scores for redness of the ground beef samples were significantly lower than those for the samples stored for 3 weeks in a chub package. The overall odour intensity of the stored samples increased ($p<0.05$) after two weeks of storage. At the same time, the intensity of the fresh beefy odour decreased and the intensity of sour and dairy odours increased significantly. There was no significant change in the intensity of painty odours during storage.

The results for the trained panel evaluation of the odour attributes of the cooked ground beef prepared in a central facility are shown in Table 4.18. The overall odour intensity of the stored samples increased and the intensity of a fresh beefy flavour decreased after two weeks of storage. At the same time, the intensity of the sour and dairy odours increased ($p<0.001$). During the three weeks of storage, there was no significant change in the intensity of stale, painty or liver odour characteristics.

Table 4.19 shows the results for the trained panel evaluation of the flavour attributes of the cooked central fine ground beef samples that had been stored in 500g chub packages. The overall flavour increased after two weeks of storage. There was no difference in the intensity of the stale, painty, liver and bitter flavour characteristics of the

Table 4.17. Mean[1] scores for the trained panel evaluation of the redness and the odour of a freshly prepared reference sample and central fine ground beef samples[2] stored at 4°C for up to 3 weeks.

Attribute		Fresly Prepared Reference	Weeks of Storage 0	1	2	3	SEM[3]
Appearance	*Redness*	10.7^{ab}	9.4^{ab}	10.3^{ab}	6.5^{b}	12.2^{a}	1.02**
Odour	*Overall*	5.8^{b}	5.7^{b}	6.4^{b}	9.2^{a}	9.8^{a}	0.26***
	Fresh Beefy	4.7^{a}	4.7^{a}	4.0^{b}	1.4^{c}	1.2^{c}	0.17***
	Painty	0.3	0.4	0.5	0.3	0.8	0.13
	Sour	0.5^{b}	0.4^{b}	1.3^{b}	4.5^{a}	4.8^{a}	0.28***
	Dairy	0.3^{b}	0.3^{b}	0.8^{b}	3.2^{a}	3.2^{a}	0.20***

1 Means are averages of 36 scores (12 panelists, 3 replications).

2 Samples were evaluated using quantitative descriptive analysis with 15 cm unstructured line scales.

3 Standard error of the mean.

abc Means within the same row sharing a common letter are not significantly different from each other, $p<0.05$.

*** Significant at $p<0.01$ and $p<0.001$, respectively.

Table 4.18. Mean[1] scores for the trained panel evaluation of the odour characteristics of a cooked, freshly prepared reference sample and cooked, central fine ground beef samples[2] stored at 4°C for 3 weeks.

Attribute	Fresly Prepared Reference	Weeks of Storage				SEM[3]
		0	1	2	3	
Overall Intensity	11.0[b]	11.0[b]	10.9[b]	12.1[a]	12.3[a]	0.23**
Fresh Beefy	9.6[a]	10.3[a]	9.4[a]	5.6[b]	4.6[b]	0.40***
Stale	0.1	0.0	0.2	0.0	0.1	0.06
Painty	0.1	0.0	0.3	0.4	0.5	0.11
Liver	0.0	0.0	0.1	0.0	0.1	0.08
Sour	0.0[b]	0.1[b]	0.1[b]	1.7[a]	1.7[a]	0.19***
Dairy	0.4[b]	0.1[b]	0.5[b]	3.7[a]	4.0[a]	0.33***

1 Means are averages of 36 scores (12 panelists, 3 replications).

2 Samples were evaluated using quantitative descriptive analysis with 15 cm unstructured line scales.

3 Standard error of the mean.

[ab] Means within the same row sharing a common letter are not significantly different from each other, $p<0.05$.

, * Significant at $p<0.01$ and $p<0.001$, respectively.

Table 4.19. Mean[1] scores for the trained panel evaluation of the flavour characteristics of a cooked, freshly prepared reference sample and cooked, central fine ground beef samples[2] stored at 4°C for 3 weeks.

Attribute	Freshly Prepared Reference	Weeks of Storage				SEM[3]
		0	1	2	3	
Overall Intensity	11.0[b]	10.9[b]	10.6[b]	12.2[a]	12.3[a]	0.22**
Fresh Beefy	9.8[a]	10.2[a]	8.5[a]	4.4[b]	4.0[b]	0.56***
Stale	0.2[b]	0.1[b]	0.6[a]	0.0[b]	0.1[b]	0.12*
Painty	0.1	0.0	0.3	0.2	0.3	0.09
Liver	0.1	0.0	0.2	0.1	0.2	0.13
Sour	0.4[c]	0.6[c]	0.5[c]	3.1[a]	2.5[b]	0.15***
Bitter	0.1	0.0	0.3	0.3	0.4	0.08
Dairy	0.4[b]	0.2[b]	0.3[b]	4.3[a]	4.4[a]	0.37***

1 Means are averages of 36 scores (12 panelists, 3 replications).

2 Samples were evaluated using quantitative descriptive analysis with 15 cm unstructured line scales.

3 Standard error of the mean.

[ab] Means within the same row sharing a common letter are not significantly different from each other, $p<0.05$.

*, **, *** Significant at $p<0.05$, $p<0.01$ and $p<0.001$, respectively.

samples stored for 0 to 3 weeks. However, the intensity of the sour and dairy flavour characteristics increased significantly after two weeks of storage.

Consumer Evaluation of Stored Ground Beef Samples Prepared by the Three Handling Systems

Samples chosen for consumer evaluation were similar in microbiological quality. The trained panel data indicated that there were differences in the odour and flavour characteristics of the specific samples chosen for presentation to consumers. According to the data obtained from the trained panel, the odour of the cooked central fine ground sample had a less intense fresh beefy odour and a more intense dairy odour than the freshly prepared reference, in-store ground and central coarse ground beef samples. The trained panel also indicated that the cooked, central fine ground sample had a less intense fresh beefy flavour and a stronger sour and dairy flavour compared with the samples prepared by the other two handling methods.

The results for the consumer evaluation of samples prepared according to each of the three handling systems and a freshly prepared reference sample are shown in Table 4.20. The panel consisted of 65 individuals of whom 48% were female and 52% were male. Of those who participated, 52% were between the ages of 18 and 25. The scores for the odour of the meatloaves prepared from fresh ground beef, central coarse ground beef and in-store ground beef were significantly higher than the scores for the meatloaf prepared from the central fine ground beef. The scores for flavour desirability and overall acceptability for the meatloaves prepared from the central fine ground beef were significantly lower than those for the meatloaves prepared from the reference sample and the in-store ground beef sample. The meatloaf prepared from the central coarse ground

Table 4.20. Mean[1] scores for the consumer evaluation of odour, flavour and overall acceptability of meatloaf prepared from a freshly ground reference sample and from central coarse, in-store and central fine ground beef samples.

Attribute	Freshly Prepared Sample	Packaging Treatment			SEM[3]
		Central Coarse[2]	In-Store Ground[2]	Central Fine[2]	
Odour	5.9[a]	5.8[a]	5.9[a]	5.2[b]	0.15**
Flavour	6.2[a]	5.7[bc]	6.1[ab]	5.4[c]	0.17**
Overall Acceptability	6.1[a]	5.7[bc]	6.0[ab]	5.3[c]	0.18**

[1] Mean of 65 panelists, scores of 9 and 1 correspond to like extremely and dislike extremely, respectively.

[2] Central coarse samples were stored in vacuum for 2 weeks with 0 days of aerobic storage; in-store ground samples were stored for 0 days; central fine samples were stored anaerobically for 2 weeks.

[3] Standard error of the mean.

[abc] Means within the same row sharing a common letter are not significantly different from each other $p<0.05$.

** Significant at $p<0.01$.

beef had significantly lower flavour desirability and overall acceptance scores than the freshly prepared reference sample.

A second consumer panel was done to compare the consumer acceptance of in-store ground beef samples stored aerobically for three days with ground beef samples prepared from coarse ground beef stored for two weeks in a chub packaged and stored aerobically for either 0 or 3 days (Table 4.21). A freshly prepared sample was also given to the consumers as a hidden control. The central coarse ground beef samples were chosen for this panel because the trained panel detected differences between the samples after two weeks of storage in a chub package. The trained panel found that the central coarse ground beef sample stored aerobically for 3 days had a less intense fresh beefy cooked odour intensity and a more intense sour flavour than the sample stored aerobically for 0 days. The consumer panel consisted of 65 individuals of whom 40% were female and 60% were male. Of those who participated, 45% were between the ages of 18 and 25. All data collected from the consumer panels were normally distributed. Consumers liked the meatloaf prepared from in-store ground beef better than that prepared from coarse ground beef and stored aerobically for either 0 or 3 days. However, the consumer panel found no significant differences in acceptability of meatloaf prepared from central coarse ground beef that had been stored for 2 weeks in a chub package and stored aerobically for 0 or 3 days.

Table 4.21. Mean[1] scores for the consumer evaluation of odour, flavour and overall acceptability of meatloaf prepared from a freshly ground reference sample, from coarse ground beef stored for 2 weeks in a chub package and stored aerobically for 0 or 3 days and from in-store ground beef stored for 3 days.

Attribute	Packaging Treatment				SEM[2]
	Freshly Prepared Reference	Central Coarse Week 2, 0 day Aerobic Storage	Central Coarse Week 2, 3 Day Aerobic Storage	In-Store Ground 3 Day Aerobic Storage	
Odour	6.0[a]	4.8[b]	5.2[b]	5.8[a]	0.17***
Flavour	6.3[a]	5.1[c]	5.3[c]	5.7[b]	0.19***
Overall Acceptability	6.2[a]	4.8[b]	5.2[b]	5.7[a]	0.18***

1 Mean of 65 panelists, scores of 9 and 1 correspond to like extremely and dislike extremely, respectively.

2 Standard error of the mean.

[abc] Means within the same row sharing a common letter are not significantly different from each other $p<0.05$.

*** Significant at $p<0.001$.

5. DISCUSSION AND CONCLUSIONS

This study was designed to evaluate the microbiological and sensory quality of ground beef prepared by three different handling systems. The quality of ground beef purchased in the retail marketplace has been criticized by the news media, thus the first part of this research evaluated products that were purchased from the retail marketplace. A comparison of the storage life of ground beef prepared by the three handling systems is lacking in the research literature, thus the second part of this project was designed to evaluate the storage life of the products using both microbiological and sensory evaluation to determine changes during storage.

In this study, central coarse and central fine ground beef available in the retail marketplace had significantly lower total, coliform and lactic acid bacterial counts than ground beef prepared from trim accumulated in the stores. This confirms the results of Shoup and Oblinger (1976) who evaluated the microbiological quality of ground beef purchased from the retail marketplace. They found that ground beef prepared in a central facility generally had lower total aerobic plate counts and lower numbers of coliforms than samples prepared in the retail store. The lower microbial load of ground beef prepared in a central operation is most likely due to less product handling and better temperature control in a central production facility. It has been demonstrated that control over storage temperature in the retail store is poor (Greer et al., 1994) and product can be stored for long periods of time due to fluctuations in sales (Gill and McGinnis, 1993). In the current study, samples that were prepared by a partially centralized process (coarse ground in a central facility and fine ground in the retail stores as needed) had the lowest microbial counts. This was somewhat surprising due to the expectation that handling in the retail marketplace would result in an increase in the microbial load on the product. In the current study on the microbiology of ground beef available for consumer purchase in the retail

market, there was no control over the storage temperature or storage time. Lack of temperature control and variations in storage times could account for some of the variation in the number of bacteria found on samples obtained for this study. It has been shown that considerable variation in the number of organisms in ground beef can be expected between, and even within, batches of ground beef (Gill and McGinnis 1993; Gamage et al., 1997).

The different types of organisms that grow as part of the microflora will have more of an effect on quality than the total number of organisms (Dainty and Mackey, 1992). Almost all meat is transported from the cutting and packaging plant to the retailer as vacuum packaged primal cuts of meat. In the retail marketplace, primal cuts are separated into retail cuts. It is this process that generates some of the trim that is used for preparation of ground beef in the retail store. The other source of trim available for in-store preparation of ground beef is trim that accumulates in a packing plant and is distributed to the retail outlet as vacuum packaged product. This means that all meat that is ground for sale in the retail outlet originates from products that were stored in a vacuum at some point in the distribution system. The use of vacuum packaging would result in a microflora dominated by LAB. It is well established that most LAB do not cause overt spoilage of meat until some time after they have reached maximum population (Borch et al., 1996; Dainty and Mackey, 1992). In this study, the majority of the organisms isolated from all of the samples, regardless of handling system, were LAB. Of the LAB, the most prevalent type were homofermentative lactobacilli. The dominance of homofermentative lactobacilli on vacuum packaged meat has been routinely demonstrated (Pierson et al., 1970; Newton and Rigg, 1979; Gardner, 1980; Hitchener et al., 1982). In contrast, in a recent study of the microbiology of ground beef packaged in a chub pack and stored at 2 and 7°C, Gamage et al. (1997) found that the predominant organisms were homofermentative lactococci. Homofermentative LAB should have less of an effect on the storage life and sensory quality of ground beef than heterofermentative lactic acid bacteria. The presence of large

numbers of heterofermentative lactic acid bacteria would result in more rapid development of a sour flavour due to the production of acetate in addition to lactate (Sutherland et al., 1976). In the current study, the samples that were obtained from the retail outlets did not have a high percentage of heterofermentative lactobacilli thus it is not surprising that the trained panel did not detect a "sour" odour or flavour in these samples. Even though LAB were the dominant microflora found on all of the ground beef samples in the retail study, other organisms that could have greater consequences for quality were isolated.

The presence of *B. thermosphacta* could have a significant effect on the storage life of ground beef. *B. thermosphacta* is known to cause dairy or cheesy characteristics in vacuum packaged meats (Borch et al., 1996) although the number of *B. thermosphacta* needed to cause detectable spoilage in meat is not clear. Central coarse ground beef samples purchased in the retail marketplace had higher numbers of *B. thermosphacta* than samples prepared either as in-store or central fine ground products. However, the trained panel data did not detect any difference in the dairy odour or flavour among the samples purchased in the retail marketplace. The number of *B. thermosphacta* may not have been high enough to cause deterioration in sensory characteristics of these samples.

Bacillus spp. were detected as part of the prevalent microflora of central coarse ground beef samples that were obtained from the retail marketplace. The presence of *Bacillus* spp. as part of the dominant microflora of ground beef has not previously been reported; however, researchers have reported an increase in the proportion of *Bacillus* spp. isolated as part of the dominant microflora of pasteurized beef (Gill and Badoni, 1997). This increase is likely the result of implementation of carcass pasteurization systems that reduce the number of viable organisms that are susceptible to heat and results in the isolation of more heat resistant organisms or endospores. The majority of *Bacillus* spp. are mesophiles and are not expected to increase in numbers in meats stored at refrigeration

temperatures. However, recently there have been reports of the isolation of psychrotrophic *Bacillus* spp. (Rowan and Anderson, 1998; Sorhaug and Stepaniak, 1997). Spores in milk may be activated by heat treatment (65 to 75°C) and may germinate (Sorhaug and Stepaniak, 1997). *B. cereus* is able to grow at temperatures as low as 6°C, and *B. circulans* can grow at temperatures as low as 2°C to cause flavour defects in milk (Meer et al., 1991). In the current study, attempts were made to trace the source of the meat used in the production of central coarse ground beef. The processor contacted indicated that the carcasses used in the production of the coarse ground beef could have come from a facility that does have a carcass pasteurizer but could not definitely confirm that the samples used in this study originated from the facility in question. The impact of high numbers of *Bacillus* spp. on the quality of ground beef in the retail marketplace is unknown. Based on the trained panel data obtained in this study, the higher proportion of *Bacillus* spp. did not have any detrimental effect on the sensory quality of ground beef. However, specific numbers of *Bacillus* spp. on individual samples was not known and conclusions about the impact of high numbers of *Bacillus* spp. on the quality of ground beef can not be made from the data gathered in this experiment. Studies specifically designed to evaluate the impact of high numbers of psychrotrophic *Bacillus* spp. on the quality of ground beef are needed before definitive conclusions can be made.

The presence and growth of high numbers of coliforms on ground beef could have severe sensory consequences for the product. Growth of *Enterobacteriaceae* has been associated with putrid spoilage of meat (Gill and Greer, 1993). There was no difference in the number of coliforms detected on the different samples collected from the retail marketplace. Storage of ground beef at low temperatures should control the growth of all coliforms and some of the *Enterobacteriaceae,* with the exception of psychrotrophic *Enterobacteriaceae* such as *Halfnia alvei* and *Serratia liquefaciens.* In a study on the

microbiology of commercially packaged coarse ground beef packaged in a chub package, Gamage et al. (1997) found that in one of three storage trials, *H. alvei* caused spoilage of chub packed ground beef. In the current study, gas production, which is a sign of spoilage due to the growth of *H. alvei* (Gamage et al., 1997) was not evident.

Although the microbiology of ground beef in the retail marketplace is variable, the impact that this has on the quality and consumer acceptance of the products may be limited due to the predominance of LAB. The first sensory characteristic that a consumer uses to make purchasing decisions is the appearance of the ground beef. Based on the data obtained in this study from the trained panel, there were some differences in the redness of the ground beef prepared by the three handling systems. The product that was prepared in the stores was scored the lowest in terms of redness by the trained panel although the data obtained from the colorimeter did not indicate differences in redness among the samples. Low correlations between visual and instrumental scores have been reported by researchers and may be due to an uneven surface discoloration of meat causing visual panels to give an average colour score (Hunt, 1980). It has also been speculated that colorimeters, by scanning a limited area of the meat surface, create a sampling problem (Hunt, 1980). Also, physical factors, such as surface topography, are often disregarded by panelists, whereas instrumental measurements are affected by physical factors.

Apart from the appearance, odour and flavour characteristics of ground beef also determine consumer acceptance. Overall, the means for the trained panel evaluation indicated that the odour and flavour characteristics of the retail samples were very similar; however, means for individual samples indicated obvious differences between specific samples. The samples for the consumer panel were chosen specifically because the trained panel indicated that differences in odour and flavour characteristics existed among the samples from the different handling systems. Although a trained panel could differentiate

among the samples, it was necessary to see if the differences would be relevant to the consumer in terms of acceptability of the different products. The consumer panel indicated that all of the samples were either liked slightly (in-store ground) or neither liked or disliked (central coarse ground and central fine ground). Thus, the differences among the samples as detected by the trained panel were not as apparent to the consumer panel. The relatively low ratings obtained from the consumer panel may have been a result of the nature of the product served to the consumers. The samples were prepared as meatloaves with no added spices, which is a product that consumers do not usually consume. This was done intentionally because the addition of spices may have masked any subtle quality differences among the samples. The small difference in the degree of liking between the in-store ground and the centrally prepared products may not be detectable to consumers using the meat in typical consumer products with other flavour ingredients added.

This study has demonstrated that there are few differences in the quality of ground beef that is prepared by the different handling systems and is available in the retail marketplace. The central coarse ground beef had the lowest average microbial load although these samples were similar in sensory characteristics to samples prepared by other handling systems. In fact, the in-store ground beef samples purchased in the retail marketplace were more well liked by the consumer panel than either the central coarse or central fine ground beef products, although on average, the in-store ground samples had the highest microbial load. This emphasizes the need for caution when relating microbial load to quality and consumer acceptance. In addition, caution must be taken in drawing a definitive conclusion that there is no difference between the handling systems for ground beef because of the lack of control over sample storage time and temperature. In this study, the source of the meat was variable and could have influenced the results. To draw conclusions on the storage life of ground beef prepared according to the three handling systems a controlled storage life study was done. Knowledge of the effects of handling

systems on the quality and storage life of ground beef will help the industry make appropriate choices of handling and packaging systems to maximize quality while minimizing economic losses due to spoilage.

A controlled storage life study was done to compare the microbiological and sensory quality and consumer acceptability of ground beef prepared by the three commercially available handling systems. In this study, the source of beef was controlled with all samples being prepared from a single source of beef trim. The beef trim used in this study was not vacuum packaged and had not been stored for any length of time at refrigeration temperatures prior to grinding in the laboratory. The ground beef prepared in the laboratory had a lower microbial load than that found in in-store ground beef purchased in the retail marketplace. This is likely due to the age and the source of the trim used in each case. In the retail market, in-store ground beef is prepared from meat that has previously been stored in vacuum packages. This meat would have an adventitious microflora of LAB. The number of organisms will depend on the temperature of storage as well as the length of storage, which can be as long as six weeks. This would explain why the ground beef used in this study had a lower bacterial load than that typically found on in-store ground beef in the retail marketplace.

Short term storage (three days) of aerobically packaged, freshly prepared ground beef at 4°C did not have any significant effect on the microbial counts of these products. Other researchers have also found that the microbial counts of ground beef do not increase by large numbers during aerobic storage at chill temperatures. In a study of the storage life of ground beef, Worobo et al. (1997) found that the total psychrotrophic and lactic acid bacteria counts of ground beef stored at 6°C in oxygen permeable packaging only increased by less than one log unit over 3 days of storage. In the current study, the sensory quality

of in-store ground beef samples did not change over the three days of storage. The trained panel did detect an increase in redness after one day of aerobic storage; however, instrumental values for redness indicated that the samples were less red after one day of aerobic storage. As previously discussed, differences between instrumental and sensory measures of meat colour are not unusual. It is difficult to explain why the values (either instrumental or sensory) for red colour may have changed after one day of storage and then reverted to values that were similar to that found at day 0. Meat colour stability can be influenced by the rate of oxygen consumption, the rate of oxidation of myoglobin in the presence of oxygen, and the enzymatic reduction of metmyoglobin (Renerre, 1990). Different samples were used for analysis on each day of storage which may have caused some variation in the results.

Ground beef prepared as central coarse ground beef that is subsequently fine ground prior to retail packaging is expected to have a superior quality compared with ground beef prepared in the retail store. In this study, there were changes in the quality of the central coarse ground beef after two weeks of storage in a chub package. This was evident from both the trained panel evaluation of redness and from the instrumental data for colour. Other sensory changes that were detected after two weeks of storage included the development of both dairy and sour odour and flavour characteristics. At the same time the panel detected these odours and flavours, the counts of *B. thermosphacta* increased to 10^3 CFU/g. *B. thermosphacta* is known to cause dairy and sour characteristics in vacuum packaged meats (Newton and Rigg, 1979, Gill and Greer, 1993). A study by Gamage et al. (1997), found that sour off-odours were noticeable in chub packaged ground beef after 7 days of storage at 2°C. However, these off-odours were detected by the individual opening the chub package. It could be that the off-odours detected by Gamage et al. (1997) were confinement odours that develop when meat is vacuum packaged and stored. Confinement odours dissipate rapidly and the meat does not retain the odour (Egan and

Shay, 1982). In the current study, panelists evaluated the odour of the product after it had been removed from the chub package and was fine ground. This would have ensured that panelists were evaluating the odour of the meat and not the confinement odours that develop in vacuum packaged meats.

As the time that coarse ground beef was stored in a chub package increased, the time for the detection of changes in quality during aerobic storage decreased. This confirms the results of other researchers (Fahner, 1998; Leisner et al., 1995; Greer et al., 1993). In the current study, the quality of at least two of the samples of central coarse ground beef stored for three weeks in a chub package had deteriorated in quality to the point that they could not be used for sensory evaluation. This is in contrast to the results of Worobo (1997) who showed that coarse ground beef stored at 4°C under vacuum for 20 days resulted in a retail storage life of 2.5 days. Differences in the initial microbial load of the meat may account for the differences in storage life observed in these two studies. Worobo (1997) used beef that had an initial microbial load of 10^3 CFU/g; whereas in the current study the beef trim had an initial microbial load of 10^4 to 10^5 CFU/g. Worobo (1997) used vacuum packaging whereas in the current study, ground beef was pulled into the chub package with a vacuum and the package was sealed at each end with clips. A vacuum was not pulled on each individual package prior to sealing with clips. In addition, the packages used by Worobo (1997) had a lower oxygen transmission rate than those used in the current study. The packages used in the current study were those that are commonly used by Alberta meat processors for chub packaging of coarse ground beef. The differences in the residual oxygen in the package and the higher oxygen transmission rate of the films would have contributed to the difference in the storage life of the products in the two experiments.

Although the increase in bacterial counts for fine ground beef during storage at 4°C was not significant because of the high variation between samples, the mean total aerobic plate count increased by two log units during storage. Since the count for lactic acid bacteria was similar to that for the total aerobic count, and because the number of *Pseudomonas* spp. did not increase during the latter stages of storage, it is likely that the oxygen content in the packages was low. The trained panel detected changes in the sensory quality of the central fine ground beef after two weeks of storage, at which time the total and LAB counts were approximately 10^6 to 10^7 CFU/g and the *B. thermosphacta* counts were approximately 10^3 CFU/g. The sensory changes that occurred during the three weeks of storage were all indicative of a deterioration in quality. Gill and Jones (1994) found that retail-ready packs of ground beef that were "master" packaged in an oxygen depleted atmosphere could have a storage life of about 30 days. This is much longer than the storage life obtained for central fine ground beef samples prepared in the current storage study. Lower storage temperatures, different packaging conditions (vacuum packaging and master packaging in high concentrations of carbon dioxide), and a lower level of initial contamination of the ground beef could account for the longer storage life obtained by Gill and Jones (1994). It is possible that meat processors may be able to extend the storage life of central fine ground beef by ensuring that a strict anaerobic environment is maintained in the package and that storage temperatures are controlled.

In the current study, the maximum microbial population reached in both the central coarse and central fine ground beef stored for 3 weeks at 4°C was approximately 10^7 CFU/g. Other researchers have found similar total microbial populations on ground beef stored in vacuum packages. In a study on the storage life of vacuum and modified atmosphere packaged ground beef, Gill and Jones (1994) found that after 8 weeks of storage at 2°C, the total microbial count was 10^6 CFU/g in products that were stored in a

vacuum package or in a package flushed with nitrogen. The maximum population of samples stored in a package flushed with CO_2 was approximately 10^7 CFU/g. Newton and Rigg (1979) found that vacuum packaged beef stored at 0°C reached a maximum population of 10^7 CFU/g after 4 weeks of storage.

Trained panel evaluation of ground beef samples provided a good assessment of the changes in quality and a description of what specific changes occurred in the samples during storage. However, the ultimate evaluation of quality is consumer acceptance. The changes in quality detected by a trained panel may not be detectable by a consumer and therefore cannot be used as an indication of the consumer acceptance of a product. However, at some point in the marketing of meat products, someone with prior knowledge of meat quality has to make a judgment on the marketability of the product. In the present storage study, consumer panels were carried out to provide a comparison to the trained panel evaluation. The central coarse and central fine ground samples chosen for consumer evaluation had been stored for two weeks at 4°C. These samples were chosen because the trained panel detected differences among the samples stored for two weeks. The consumer panel was able to detect differences among the samples. Samples that were prepared as in-store ground or central coarse ground beef were rated as "like slightly" and the samples prepared as central fine grind as "neither like nor dislike". Ground beef prepared as in-store grind was not stored for any length of time prior to presentation to the consumer panel; therefore it is not surprising that these samples were scored as the most acceptable. The odour of the central fine ground beef sample was considered to be the least acceptable. Lynch et al. (1986) conducted a study the acceptability of ground beef packaged in either aerobic packages with polyvinyl chloride (PVC) or vacuum packages (VP). In their study, trim was fine ground, packaged, and stored at 1°C. Preference testing by 58 consumer panelists indicated that panelists preferred the flavour of the aerobically packaged ground

beef that had been stored for 3 days over the flavour of vacuum packaged ground beef that had been stored for 12 days. The mean scores that Lynch et al. (1986) obtained from consumers for their samples ranged from "like slightly" to "like moderately" which are similar to those obtained in the present study. The results of Lynch et al. (1986) are similar to those of the current study that also indicated that consumers preferred freshly ground, aerobically packaged ground beef samples to those that had been stored for two weeks as fine ground beef in a chub package. These results may have implications for meat processors who are trying to optimize the storage life and consumer acceptability of their products.

A second consumer panel was done to compare the impact of aerobic storage on consumer acceptance of ground beef. The time that aerobically packaged meat sits in a display case could affect the consumer acceptance of the ground beef. The consumer panel did not indicate that aerobic storage for 3 days would have any effect on product acceptability. This is in contrast to the results of the trained panel that found that the intensity of specific characteristics that are indicative of spoilage increased during the three days of aerobic storage. These results can be explained by the fact that a consumer is not trained to detect specific sensory characteristics in ground beef and they would not be as sensitive to flavour differences as a trained panel.

This research has shown that there are some differences in the sensory characteristics of ground beef prepared by different handling systems, although these differences are not easily detected by consumers. In the retail study, the microbiological quality of the samples was extremely variable; however, the in-store ground beef generally had the highest microbial load. In both the retail study and the storage study, consumers indicated that they preferred the in-store ground beef and central coarse ground beef to the central fine ground product. With the implementation of new packaging systems, the

central preparation of ground beef technologies has become important in the distribution and marketing of ground beef. Although consumers preferred in-store ground beef over the central fine ground beef, economically, there may be disadvantages with in-store preparation of ground beef compared with centralized preparation. The costs of extra labour, equipment and facilities in the retail marketplace must be considered as economic disadvantages to in-store preparation of ground beef. In the distribution and marketing of ground beef, when product is prepared in the retail outlets, the storage life is limited to the case life of the product on retail display. However, central preparation and packaging of coarse ground beef in a chub package can extend the storage life to at least two weeks prior to placing the product on retail display. The results of this study show that central preparation of coarse ground beef can provide retailers with a product that is comparable to freshly ground beef produced from trim. The central preparation of ground beef involves little or no handling in the retail stores. The processing conditions in a central facility can be more strictly controlled than processing conditions in the retail marketplace. Centrally prepared ground beef allows meat processors to expand their retail markets and distribute product into markets that could not be accessed in the past. Although centrally prepared fine ground beef was not the optimal choice for maximizing storage life, the opportunity for product branding must be considered as an advantage to this handling system.

6. BIBLIOGRAPHY

Adams, J.R. and D.L Huffman. 1972. Effect of controlled gas atmospheres and temperature on quality of packaged pork. J. Food Sci. 37:869-872.

American Meat Science Association. 1995. Guidelines for Cookery and Sensory Evaluation of Meat. American Meat Science Association.

Ayres, J.C. 1960. Temperature relationships and some other characteristics of microbial flora developing on refrigerated beef. Food Res. 25:1-18.

Blickstad, E. and G. Molin. 1983. Carbon dioxide as a controller of the spoilage flora of pork, with special reference to temperature and sodium chloride. J. Food Prot. 46:756-763.

Borch, E., M.L. Kant-Muermans, and Y. Blixt. 1996. Bacterial spoilage of meat and cured meat products. Int. J. Food Microbiol. 33:103-120.

Breidenstein, B.B. 1986. Economic impact of meat spoilage organisms. Proc. 39th Ann. Recip. Meat Conf. Vol 39, pp.1-4.

Chambers, E. IV and J.R. Bowers. 1993. Consumer perception of sensory qualities in muscle foods. Food Technol. 47(11):116-120.

Dainty, R.H. and C.M. Hibbard. 1980. Aerobic metabolism of *Brochothrix thermosphacta* growing on meat surfaces and in laboratory media. J. Appl. Bacteriol. 48:387-396.

Dainty, R.H. and B.M. Mackey. 1992. The relationship between the phenotypic properties of bacteria from chill-stored meat and spoilage processes. J. Appl. Bacteriol. 73:103S-114S.

Dainty, R.H., R.A. Edwards and C. Hibbard. 1985. Time course of volatile compound formation during refrigerated storage of naturally contaminated beef in air. J. Appl. Bacteriol. 59:303-309.

Dainty, R.H., R.A. Edwards and C. Hibbard. 1989. Spoilage of vacuum-packed beef by a *Clostridium* sp. J. Sci. Food Agric. 49:473-486.

Dainty, R.H., B.G. Shaw and T.A. Roberts. 1983. Microbial and chemical changes in chill-stored red meats, pp. 151-178. *In* T.A. Roberts and F.A. Skinner (editors), Food Microbiology: Advances and Prospects. Academic Press, Toronto.

Dainty, R.H., B.G. Shaw T.A. Roberts and J.J. Marnewick. 1989. Volatile compounds associated with microbial growth on normal and high pH beef stored at chill temperatures. J. Appl. Bacteriol. 66:281-289.

Daniels, J.A., R. Krishnamurthi and S.S.H. Rizvi. 1985. A review of effects of carbon dioxide on microbial growth and food quality. J. Food Prot. 48:532-537.

Duitschaever, C.L., D.R. Arnott and D.H. Bullock. 1973. Bacteriological quality of raw refrigerated ground beef. J. Milk Food Technol. 36:375-377.

Egan, A.F. and B.J. Shay. 1982. Significance of lactobacilli and film permeability in the spoilage of vacuum-packaged beef. J. Food Sci. 47:1119-1122, 1126.

Emswiler, B.S., C.J. Pierson and A.W. Kotula. 1976. Bacteriological quality and shelf life of ground beef. Appl. Environ. Microbiol. 31:826-830.

Enfors, S.-O., G. Molin, and A. Ternstrôm. 1979. Effect of packaging under carbon dioxide, nitrogen or air on the microbial flora of pork stored at 4°C. J. Appl. Bacteriol. 47:197-208.

Fahner, K. 1998. Characterization and evaluation of a commercial pork packaging process. MSc thesis. University of Alberta.

Gamage, S.D., N.G. Faith, J.B. Luchansky, D.R. Buege and S.C. Ingham. 1997. Inhibition of microbial growth in chub-packaged ground beef by refrigeration (2°C) and medium-dose (2.2 to 2.4 kGy) irradiation. Int. J. Food Microbiol. 37:175-182.

Gardner, G.A. 1966. A selective medium for the enumeration of *Microbacterium thermosphacta* in meat and meat products. J. Appl. Bacteriol. 29:455-460.

Gardner, G.A. 1980. *Brochothrix thermosphacta* (*Microbacterium thermosphactum)* in the spoilage of meats: a review, pp. 139-173. *In* T.A. Roberts, G. Hobbs, J.H.B. Christian and N. Skovgaard (editors), Psychrotrophic Microorganisms in Spoilage and Pathogenicity. Academic Press, Toronto.

Gawehn, K. 1984. D(-)-Lactate, pp. 588-592. *In* H.U. Bergmeyer (ed.), Methods of Enzymatic Analysis, 3rd ed., Metabolites 1: Carbohydrates, Verlag Chemie, Weinheim.

Gill, C.O. and M. Badoni. 1997. The hygienic and organoleptic qualities of ground beef prepared from manufacturing beef pasteurized by immersion in hot water. Meat Sci. 46:67-75.

Gill, C.O. and G.G. Greer. 1993. Enumeration and identification of meat spoilage bacteria. Lacombe Technical Bulletin No. 6. Minister of Supply and Services, Canada.

Gill, C.O. and S.D.M. Jones. 1992. Efficiency of a commercial process for the storage and distribution of vacuum-packaged beef. J. Food Prot. 55:880-887.

Gill, C.O. and T. Jones. 1994. The display of retail packs of ground beef after their storage in master packages under various atmospheres. Meat Sciece 37:281-295.

Gill, C.O. and C. McGinnis. 1993. Changes in the microflora on commercial beef trimmings during their collection, distribution and preparation for retail sale as ground beef. Int. J. Food Microbiol. 18:321-332.

Gill, C.O. and G. Molin. 1991. Modified atmospheres and vacuum packaging pp. 172-199. *In*. N.J. Rusell and G.W. Gould (editors), Food Preservatives. Blackie, Glasgow.

Gill, C.O. and K.G. Newton. 1978. The ecology of bacterial spoilage of fresh meat at chill temperatures. Meat Sci. 2:207-217.

Gill, C.O. and N. Penney. 1986. Packaging conditions for extended storage of chilled dark, firm, dry beef. Meat Sci. 18:41-53.

Gill, C.O., G.G. Greer and B.D. Dilts. 1998. Predicting the growth of *Escherichia coli* on displayed pork. Food Microbiol. 15:235-242.

Greenberg, R.A., R.B. Tompkin, B.O. Bladel, R.S. Kittaka and A. Anellis. 1966. Incidence of mesophilic *Clostridium* spores in raw pork, beef and chicken in processing plants in the United States and Canada. Appl. Microbiol. 15:789-793.

Greer, G.G., C.O. Gill and B.D. Dilts. 1994. Evaluation of the bacteriological consequences of the temperature regimes experienced by fresh chilled meat during display. Food Res. Int. 27:371-377.

Greer, G.G. and A.C. Murray. 1988. Effects of pork muscle quality on bacterial growth and retail case life. Meat Sci. 24:61-71.

Hammes, W.P., A. Bantleon and S. Min. 1990. Lactic acid bacteria in meat fermentation. FEMS Microbiol. Rev. 87:165-174.

Hastings, J.W. and M.E. Stiles. 1991. Antibiosis of *Leuconostoc gelidum* isolated from meat. J. Appl. Bacteriol. 70:127-134.

Hauschild, A.H.W., L.N. Poste and R. Hilsheimer. 1985. Toxin production by *Clostridium botulinum* and organoleptic changes in vacuum-packaged raw beef. J. Food Prot. 48:712-716.

Hitchener, B.J., A.F. Egan and P.J. Rogers. 1982. Characteristics of lactic acid bacteria isolated from vacuum-packaged beef. J. Appl. Bacteriol. 52:31-37.

Hunt, M.C. 1980. Meat color measurements. Proc. Recip. Meat. Conf. 33:41-46.

Ingram, M. 1962. Microbiological principles in prepacking meats. J. Appl. Bacteriol. 25: 259-281.

Ingram, M. and R.H. Dainty. 1971. Changes caused by microbes in spoilage of meats. J. Appl. Bacteriol. 34:21-39.

James, S.J. and C. Bailey. 1990. Chilling systems for foods, pp. 1-36. *In* T.R. Gormley (editor), Chilled Foods: the State of the Art. Elsevier Applied Science, London.

Jay, J.M. 1992. Modern Food Microbiology. 4th ed. Chapman & Hall. New York, NY.

Jeremiah, L.E. and G.G. Greer. 1982. Color and discoloration standards for retail beef and veal. Publication 1734. Agriculture Canada.

Joyner, N.T. and J.E. McIntyre. 1938. The oven test as an index of keeping quality. Oil and Soap 15:184.

Kalchayanand, N., B. Ray, R.A. Field, and M.C. Johnson. 1989. Spoilage of vacuum packaged refrigerated beef by *Clostridium*. J. Food Prot. 52:424-426.

King, A.D. and C.W. Nagel. 1975. Influence of carbon dioxide upon the metabolism of *Pseudomonas aeruginosa*. J. Food Sci. 40:362-366.

Krieg, N.R. and J.G. Holt. 1986. Bergey's Manual of Systematic Bacteriology, Vol. 1, Williams and Wilkins, Baltimore, MD.

Lawrie, R.A. 1974. Meat Science, 2nd Ed. pp. 293-297. Pergamon Press, New York.

Lawrie, R.A. 1991. Meat Science, 5th Ed. pp. 184-224. Pergamon Press, New York.

Leisner, J.J., G.G. Greer, B.D. Dilts and M.E. Stiles. 1995. Effect of growth of selected lactic acid bacteria on storage life of beef stored under vacuum and in air. Int. J. Food Micorbiol. 26:231-243.

Lynch, N.M., C.L. Kastner, D.H. Kropf and J.F. Caul. 1986. Flavor and aroma influences on acceptance of polyvinyl chloride versus vacuum packaged ground beef. J. Food Sci. 51:256-257.

Mattila-Sandholm, T. and E. Skyttä. 1991. The effect of spoilage flora on the growth of food pathogens in minced meat stored at chilled temperature. Lebensm-Wiss Technol. 24:116-120.

McMullen, L. and M.E. Stiles. 1993. Microbial ecology of fresh pork stored under modified atmosphere at -1, 4.4 and 10°C. Int. J. Food Microbiol. 18:1-14.

Mead, G.C. and B.W. Adams. 1977. A selective medium for the rapid isolation of pseudomonads associated with poultry meat spoilage. Brit. Poult. Sci. 18:661-670.

Meer, R.R., J. Baker, F.W. Bodyfelt and M.W. Griffiths. 1991. Psychrotrophic *Bacillus* spp. in fluid milk products: A Review. J. Food Protect. 54:969-979.

Meilgaard, M., G. Vance Civille and B.T. Carr. 1987. Sensory Evaluation Techniques Volume I. CRC Press, Inc. Boca Raton, Florida.

Newton, K.G. and W.J. Rigg. 1979. The effect of film permeability on the storage life and microbiology of vacuum-packed meat. J. Appl. Bacteriol. 47:433-441.

Noll, F. 1984. L(+)-Lactate, pp. 582-588. *In* H.U. Bergmeyer (ed.), Methods of Enzymatic Analysis, 3rd ed., Metabolites 1: Carbohydrates, Verlag Chemie, Weinheim.

Nychas, G.J., Viv. M. Dillon and R.G. Board. 1988. Glucose, the key substrate in the microbiological changes occuring in meat and certain meat products. Biotech. and Applied Biochem. 10:203-231.

Pierson, M.D., D.L. Collins-Thompsom and Z.J. Ordal. 1970. Microbiology, sensory and pigment changes of aerobically and anaerobically packaged beef. Food Technol. 24:1171-1175.

Pirko, P.C. and J.C. Ayres. 1957. Pigment changes in packaged beef during storage. Food Technol. 11(9):461-468.

Reagan, J.O., G.C. Smith and Z.L. Carpenter. 1973. Use of ultraviolet light for extending the retail caselife of beef. J. Food Sci. 38:929-931.

Renerre, M. 1990. Review: Factors involved in the discoloration of beef meat. Int. J. Food Sci. Technol. 25:613-630.

Reuter, G. 1980. Psychrotrophic lactobacilli in meat products, pp. 253-257. *In* T.A. Roberts, G. Hobbs, J.H.B. Christian and N. Skovgaard (editors), Psychrotrophic Microorganisms in Spoilage and Pathogenicity. Academic Press, Toronto.

Ridell, J. and H. Korkeala. 1997. Minimum growth temperatures of *Hafnia alvei* and other *Enterobacteriaceae* isolated from refrigerated meat determined with a temperature gradient incubator. Int. J. Food Microbiol. 35:287-292.

Rogosa, M., J.A. Mitchell and R.F. Wiseman. 1951. A selective medium for the isolation of oral and faecal lactobacilli. J. Bacteriol. 62:132-133.

Rousset, S. and M. Renerre. 1991. Effect of CO_2 or vacuum packaging on normal and high pH meat shelf-life. Int. J. Food Sci. Technol. 26:641-652.

Rowan, N.J. and J.G. Anderson. 1998. Diarrhoeal enterotoxin production by psychrotrophic *Bacillus cereus* in reconstituted milk-based infant formula (MIF). Lett. in Appl. Microbiol. 26:161-165.

SAS Institute. 1989. SAS User's Guide: Statistics. SAS Institute, Inc., Cary, NC.

Schillinger, U. and F.-K. Lücke. 1987. Identification of lactobacilli from meat and meat products. Food Microbiol. 4:199-208.

Schillinger, U. and F.-K Lücke. 1989. Antibacterial activity of *Lactobacillus sake* isolated from meat. Appl. Environ. Microbiol. 55:1901-1906.

Seideman, S.C., H.R. Cross, G.C Smith and P.R. Durland. 1984. Factors associated with fresh meat color: a review. J. Food Quality 6:211-237.

Seideman, S.C. and P.R. Durland. 1983. Vacuum packaging of fresh beef: a review. J. Food Quality 6:29-47.

Shaw, B.G. and C.D.Harding. 1984. A numerical taxonomic study of lactic acid bacteria from vacuum-packed beef, pork, lamb and bacon. J. Appl. Bacteriol. 56:25-40.

Shaw, B.G. and C.D. Harding. 1985. Atypical lactobacilli from vacuum-packaged meats: comparison by DNA hybridization, cell composition and biochemical tests with a description of *Lactobacillus carnis* sp. nov. System. Appl. Microbiol. 6:291-297.

Shay, B.J. and A.F. Egan. 1981. Hydrogen sulphide production and spoilage of vacuum-packaged beef by *Lactobacillus*, pp. 241-251. *In* T.A. Roberts, G. Hobbs, J.H.B. Christian and N. Skovgaard (editors), Psychrotrophic Microorganisms in Spoilage and Pathogenicity. Academic Press, Toronto.

Shay, B.J. and A.F. Egan. 1986. Studies of possible techniques for extending the storage life of chilled pork. Food Technol. Aust. 38:144-146.

Shoup, J.G. and J.L. Oblinger. 1976. Microbiological evaluation of retail ground beef: centralized and traditional preparation. J. Milk Food Technol. 39:179-183.

Singh, U. 1998. Isolation and identification of *Aeromonas* spp. from ground meats in Eastern Canada. J. Food Prot. 60:125-130.

Sorhaug, T. and L. Stepaniak, 1997. Psychrotrophs and their enzymes in milk and dairy products: Quality aspects. Trends food Sci. Technol. 8:35-41.

Steele, R.G.D. and J.H. Torrie. 1980. Principles and Procedures of Statistics: A Biometrical Approach, Second Edition. McGraw-Hill Book Co., Toronto.

Stiles, M.E. and J.W. Hastings. 1991. Bacteriocin production by lactic acid bacteria: potential for use in meat preservation. Trends in Food Technol. 2:247-251.

Sutherland, J.P., J.T. Patterson and J.G.Murray. 1975. Changes in the microbiology of vacuum-packaged beef. J. Appl. Bacteriol. 39:227-237.

Sutherland, J.P., P.A. Gibbs, J.T. Patterson and J.G. Murray. 1976. Biochemical changes in vacuum packaged beef occurring during storage at 0-2°C. J. Food Technol. 11:171-180.

Tan, K.H. and C.O. Gill. 1982. Physiological basis of CO_2 inhibition of a meat spoilage bacterium, *Pseudomonas fluorescens*. Meat Sci. 7:9-17.

Walters, C.L. 1975. Meat colour: the importance of heam chemistry. pp.385-401. In D.J.A. Cole and R.A. Lawrie (ed.), Meat. AVI Publishing Co., Westport, Conn.

Wilkinson, B.J. and D. Jones. 1977. A numerical taxonomic survey of *Listeria* and related bacteria. J. Gen. Microbiol. 98:399-421.

Worobo, R.J. 1997. Ground Beef Quality and Extended Storage Life. MSc Thesis, University of Alberta.

Worobo, R.J., M.E. Stiles, G.G. Greer and R. Lower. 1997. The case life of ground beef can be greater than one day. Dairy, Food and Environ. Sanit. 17:644-650.

Young E. and B.C. Fitz-James. 1959. Chemical and morphological studies of bacterial spores formation. II. Spore and parasporal protein formation in *Bacillus cereus* var. *alesti*. J. Biophys. Biochem. Cytol. 6:483-498.

Young, L.L., R.D. Reviere and A.B. Cole. 1988. Fresh red meats: a place to apply modified atmospheres. Food Technol. 42(9):65-69.